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IN
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A FIRST COURSE

IN

PLANT AND ANIMAL BIOLOGY

BY

W. S. FURNEAUX

AUTHOR OF "HUMAN PHYSIOLOGY," "ELEMENTARY CHEMISTRY," "THE OUTDOOR WORLD," BRITISH BUTTERFLIES AND MOTHS," "LIFE IN PONDS AND STREAMS," "THE SEASHORE," ETC.

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PREFACE.

The object of this little work is to supply the beginner with an introductory guide to the study of Animal and Vegetable Life. It is an attempt to provide such a simple and yet practical and scientific treatment of a few selected types of plants and animals as will lead to a clearer understanding of the more advanced works that may be subsequently studied.

A perusal of the following pages will show that no attempt has been made to present a multitude of facts to be learnt at home or in the class-room, but rather to deal broadly with the more obvious features that characterise living beings, and to stimulate the student to make original and careful observations of all natural objects that come within his reach.

The book deals with living Nature rather than with dead objects. The student is recommended to watch the development of plants and their various organs; to note how their structure is adapted to their habits, and how both structure and habit may vary in accordance with their habitats and environments. Animals are also dealt with as living things, special regard being paid to their movements and mode of life, while internal structure is described only so far as it is necessary in order to explain these movements and habits. But little attention, too, is paid to microscopic structure, though it has been considered necessary to deal with a few minute forms, mainly with the object of making clear the chief distinctions between plants and animals.

It is obvious that the study of natural objects is essentially an out-door study, and the reader can never become a real student of nature unless he is prepared to spend much time in the open, armed with note-book, sketch-book, pocket lens, and, above all, a determination to closely observe and to faithfully record all the observations made.

In the second edition an Appendix giving suggestions for practical work has been added.

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SECTION I.—GENERAL BIOLOGY.

CHAPTER I.

THE AMŒBA.

If we collect a small quantity of water, together with some of the sediment, from a stagnant pool, place a single drop of it on a glass slip, cover it with a "cover-glass," and examine it under a compound microscope, we shall probably find that it contains little moving masses of transparent substance, resembling a colourless jelly, of a granular appearance within, but clear towards the surface. As we watch them we note that they are continually changing in shape by thrusting out prolongations of their substance in various directions, and slowly dragging themselves along by means of the temporary processes thus formed.

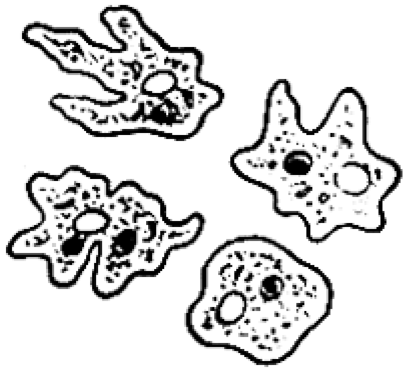

Fig. 1.—Amœba Magnified.

These minute bodies are living beings, known as *Amœbæ*, and occur almost everywhere in stagnant water and in wet soil. They may be obtained with ease during the summer by pouring hot water on a small quantity of hay or other vegetable matter, and leaving the infusion exposed to air for some days.

They vary considerably in size—from 1-1000th to over 1-100th of an inch in diameter—the largest specimens being easily seen with the aid of an ordinary hand lens.

A further examination of an active amœba will show that the prolongations thrust out from its body consist at first entirely of the clear outer portion, and that the granular interior, which is less solid, afterwards flows into them, often somewhat suddenly. We may also observe little spaces in the interior containing water, and, generally, one or two rounded masses of firmer consistence called *nuclei.* Further, in the outer and clear portion of the substance is a distinct cavity which alternately dilates slowly and then suddenly contracts, the contraction being generally so complete that the cavity quite disappears for a time.

The amœba has no mouth or other external opening, but if it comes into contact with a nutritious particle, such as a minute vegetable organism, the latter will penetrate into the interior of the amœba, the clear substance of which will recover its continuity as soon as the particle has passed through it. The food material thus obtained is digested by the softer matter of the interior; and, after some time, the undigested portions of the meal pass out through the outer layer much in the same manner as the entry was made.

The manner in which this little being multiplies may also be readily observed. The nucleus at first divides into two, and this is followed by a similar division of the softer substance around it, till, at last, two similar amœbæ have been formed from the one.

If the water containing amœbæ is allowed to cool down to the freezing point all movements are arrested; but, even if kept in this dormant condition for a long time, the amœbæ will resume their activity as soon as a favourable temperature has been restored. The movements are most active at a temperature of from 80° to 90° F., but are permanently stopped, and the organisms killed, at about twenty degrees above blood-heat.

The amœba consists principally of water and a substance called *protoplasm*—a substance made up of carbon, hydrogen, oxygen, and nitrogen, with small proportions of sulphur, phosphorus, and a few other elementary bodies. This protoplasm is a very complex chemical compound, most intimately connected with life, for it is found to occur in every living being of both the animal and vegetable worlds. It is known also that oxygen is necessary to the amœba, and that carbonic acid gas is evolved by it.

So far we have spoken of the amœba simply as a living being, but presently we shall have to decide the important question as to whether it is an animal or a plant. The reader will probably decide at once in favour of the former on the ground that the amœba moves, but we have yet to learn that some of the low forms of vegetable life move very freely, as do also parts of some of the more highly organised plants. It may also be well to state at once that it is not at all easy, and, in some cases, even impossible, to decide this question with regard to certain simple forms of living beings. For the present, however, it should be borne in mind that the amœba has no power to build up its protoplasm from elements obtained from simple inorganic or mineral substances, but that it can feed only on protoplasmic matter that has already been manufactured by other living things.

Finally, it is interesting to note that little bodies or *cells* closely resembling the amœba in structure and movements occur in human blood and in the blood of other animals. They are known as the *colourless corpuscles*, and may be readily observed by examining a minute drop of blood, spread out between a glass slip and a cover-glass, under the high power of a microscope. In the case of the blood of a cold-blooded animal, such as the frog, these corpuscles may be kept alive and under observation for days.

CHAPTER II.

YEAST.

In order to study another of the simplest forms of life we obtain a small quantity of brewers' yeast, strain it through fine muslin, add a little sugar, and set it aside in a warm place. If we now examine the liquid from time to time, we observe that bubbles of gas rise rapidly to the surface forming a froth, that its sweetness is gradually lost, and that it assumes a spirituous odour. By pouring the liquid into a flask fitted with a cork and a bent delivery tube (Fig. 2) we can conduct the evolved gas into a vessel of lime-water; and then, as the gas bubbles through the lime-water, a white precipitate is formed, showing that it is carbonic acid gas. Also, if we pour the liquid into a glass retort after the action has been allowed to continue for several hours, boil away a small portion of it, and condense the vapour in a cool receiver (Fig. 3), we shall find that the small quantity thus distilled possesses the characteristic odour, burning taste, and intoxicating property of alcohol. The sugar has, in fact, been acted on by the yeast, and split up into alcohol and carbonic acid gas. The action is termed *fermentation*.

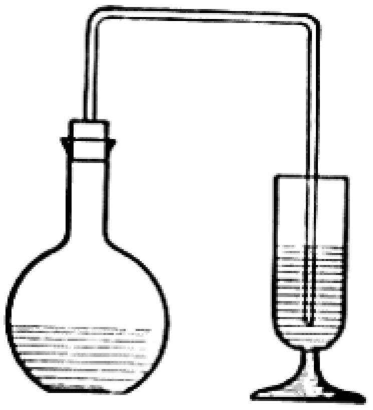
Fig. 2.—Apparatus for studying the fermentation of yeast.

If we evaporate some yeast at a very gentle heat we obtain a dry powdery mass which still retains its power of producing the above change when it is placed in a warm solution of sugar; but if we heat it up to the boiling temperature of water this power is entirely lost. Further, if we boil some yeast to kill it, and then pour half of it into each of two bottles, afterwards plugging the mouth of one with cotton wool, and setting both aside for future observation, we note that the action above described commences after a time in the bottle that has been left open, but not in the other.

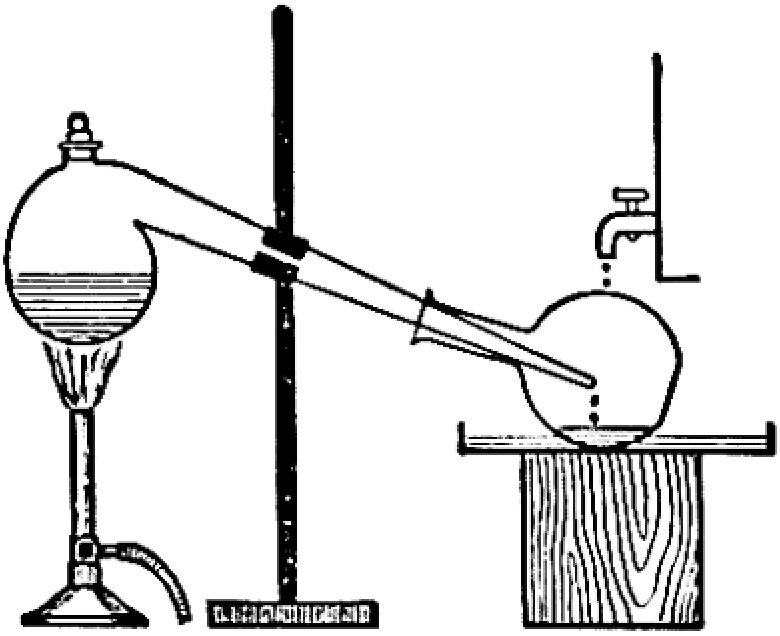

Fig. 3.—Apparatus for Distillation.

The above observations prove that there is something in the yeast capable of producing fermentation; that this substance retains this power even when dried; that its power is destroyed when the substance is heated to the temperature of boiling water; also that this substance is carried about in the air, but is unable to penetrate a plug of cotton wool.

To determine the nature of the substance referred to we examine a drop of yeast under the microscope, when it is seen to consist of a clear liquid in which floats a multitude of little round or oval bodies of variable size, but much smaller than the amœba, being only about 1-3000th of an inch in diameter.

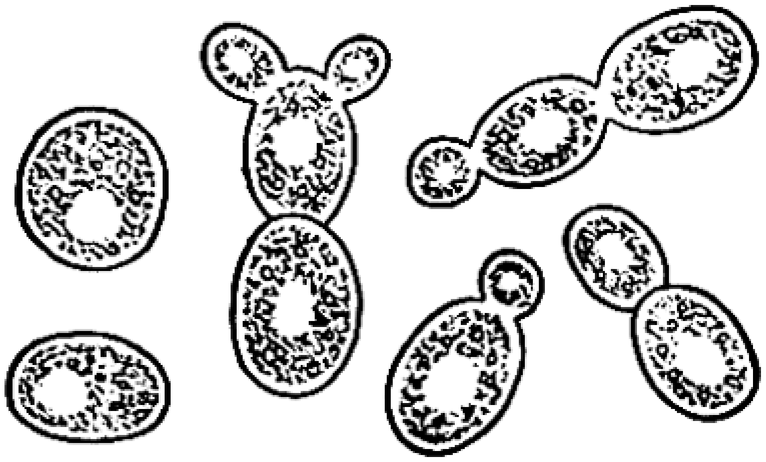

Fig. 4.—Yeast Cells Highly Magnified.

Some of the bodies float singly, while others are connected in strings or masses. Each one is a minute "cell," consisting of a thin but firm wall, surrounding a fluid interior that contains protoplasm, often with a clear watery space.

The yeast cells are little *living* beings, capable of growing and reproducing their kind. The growth is not superficial, as is the case with crystals of mineral substances, but the additions are made internally, as with animals and vegetables.

The process of multiplication goes on rapidly and may be watched under the microscope. When the yeast is active certain of the cells may be seen to produce little globular "buds" which grow till they reach the size of the parent cells. These generally produce other buds while still attached to the original cell, and the progeny may be set free as independent organisms when fully grown, or they may remain attached to their parent cells, thus forming the strings or masses of cells above referred to.

Another method of multiplication may be observed in the case of yeast cells. The protoplasm of a cell divides into distinct parts, usually four in number, and a cell-wall is then formed around each. Eventually the wall of the parent cell dissolves away, and the little masses within are set free as *spores.* These spores retain their vitality for a considerable time, even when perfectly dry. They are easily wafted about by the atmosphere, and develop into active yeast cells whenever they reach a suitable nourishing fluid.

All yeast cells are produced by one of the methods of multiplication just described, none being produced except as the offspring of a mother cell.

We have seen that the yeast cell consists of a definite and firm wall filled with a fluid interior. The wall is composed of a substance called *cellulose,* which consists of the elements carbon, hydrogen, and oxygen. The contents are made up of water, protoplasm, fat, and a small quantity of mineral matter.

Food is necessary for its growth and development; but, unlike the amœba, it does not require to have its protoplasm ready made, for it has the power of building up this complex and essential material from the elements contained in much simpler mineral compounds. Organic matter, such as sugar, is also essential, but this does not provide material for the construction of protoplasm, since it contains carbon, hydrogen, and oxygen only. The cellulose, protoplasm, and fat of the cell are constructed entirely from the elements of mineral matter dissolved in the surrounding fluid, while the sugar provides only the energy of the organism.

It will thus be seen that yeast cells could not live in pure water, which consists of hydrogen and oxygen only, nor in water containing nothing but dissolved sugar; but, if we add certain mineral salts that contain the necessary elements, the growth and multiplication of the cells will proceed rapidly in the fluid, providing a suitable temperature is maintained.

Such a fluid may be prepared by adding small quantities of the following salts to a solution of sugar:—

Ammonium tartrate (containing nitrogen, hydrogen, carbon, and oxygen).
Magnesium sulphate (containing magnesium, sulphur, and oxygen).
Calcium phosphate (containing calcium, phosphorus, and oxygen).
Potassium phosphate (containing potassium, phosphorus, and oxygen).

This fluid contains no protoplasm, fat, or cellulose; therefore it is clear that these substances must be built up from the elements of the less complicated compounds dissolved in it.

It should also be noted that active yeast cells absorb oxygen, and that light is not essential to their growth and multiplication. These and other facts previously stated should be remembered when we consider, as we shall do presently, whether yeast should be classified with animal or vegetable life.

CHAPTER III.

PROTOCOCCUS.

REMOVE a small quantity of the green scum that may be found on the wet surface of a water-butt, on the deposit in a roof-gutter, or on the moist surfaces of palings and tree-trunks. Put it in a drop of water, and examine it under the high power of a microscope.

It consists of little spherical cells, varying from 1-400th to 1-4000th of an inch in diameter, each composed of a firm transparent wall surrounding a soft granular substance.

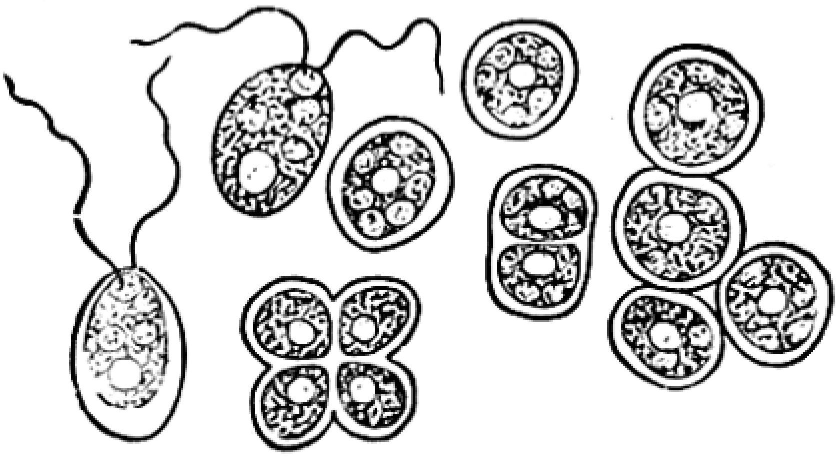

Fig. 5.—PROTOCOCCUS HIGHLY MAGNIFIED.

The cell-wall consists principally of cellulose—the same substance that forms the wall of the yeast cell, and the principal ingredient of the contents is protoplasm. A little mass of denser protoplasm forms a nucleus in the centre of the cell, and the softer portion surrounding the nucleus contains little masses of protoplasm that enclose a green colouring matter called *chlorophyll*, and sometimes also a red colouring matter.

If we mount some of the cells (called *protococci*) in a drop of weak iodine solution we find that there are yet other granules which are turned blue by the iodine. These are granules of starch— a substance that may always be identified by the blue colour thus produced,

In some of the protococcus cells we may observe that the contents have divided into little globular masses which have no walls. These are afterwards set free, and become active *spores*. They have little hairlike projections (called *cilia*) which vibrate rapidly—so rapidly that they are invisible unless some means be adopted to restrain their motion. As a result the spores swim about actively with a rotatory as well as a progressive motion. A study of their movements under varying conditions will show that they are sensitive to light, for they always swim towards a moderate light, but away from the light when it is very intense.

After a period of activity the spores lose their cilia and become enclosed in a cell-wall, thus assuming a form identical with that of the parent cells which produced them. If they become dry they still retain their power of developing; and in this condition they are readily carried about by the wind until they come into contact with water or a moist surface, when they adhere, and, if circumstances are favourable, develop into protococcus cells. Thus we can account for the abundance of the green deposit formed on the roofs and gutters of houses, palings, and other exposed moist surfaces.

Sunlight is essential to the development of protococcus, and a very important work is carried on during the daytime by the chlorophyll it contains. This substance has the power, under the influence of light, of decomposing the carbonic acid gas absorbed by the cell from the surrounding air or water. The carbon obtained from this source becomes fixed by the cell, and helps to build up the protoplasm, fat, and cellulose, while the oxygen is set free.

This action may be demonstrated by filling a cylindrical glass jar with water that has been saturated with carbonic acid gas, putting into it a quantity of protococcus, fixing an inverted funnel, provided with tube and clip, as shown in Fig. 6, and exposing the whole to sunlight. The carbonic acid gas will be gradually absorbed from the water, while numerous small bubbles of gas will be seen to rise. If, after sufficient of this gas has been formed, we release the clip, and place a glowing splint in the stream of gas as it escapes, the ignition of the spark will show that it is oxygen. This same action is produced by all green plants, and a much better result may be obtained by substituting one of our common aquatic plants for protococcus.

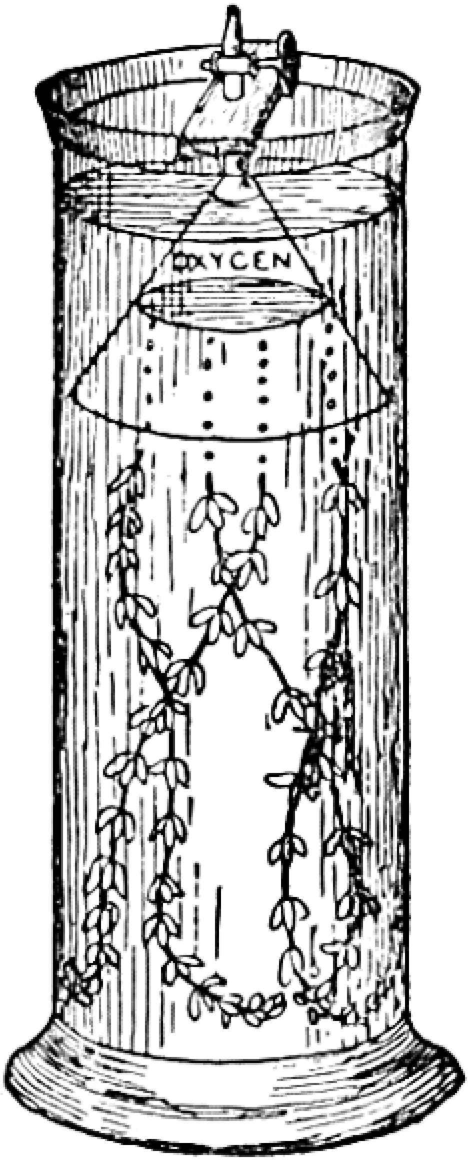

Fig. 6.—APPARATUS FOR DEMONSTRATING THE EVOLUTION OF OXYGEN FROM A GREEN PLANT EXPOSED TO SUNLIGHT.

Protococcus, like yeast cells, has the power of building up its protoplasm and other organic compounds from elements derived from mineral salts. Such salts are always present more or less in all natural waters, and some (ammonium salts) even exist in the atmosphere in small quantities. They are necessary for the growth and development of the organism; hence protococcus cannot be cultivated in pure water, but thrives well in a solution containing the compounds recommended for the cultivation of yeast. But here is an important difference between the two forms of life, for while yeast cells require organic matter (sugar), protococcus is able to thrive and build up its substance entirely from carbonic acid gas and simple mineral compounds.

It has been observed that yeast cells absorb oxygen and give out carbonic acid gas. This is also true of protococcus, at least during darkness, and perhaps also in the daytime; but this action is only slight, and the amount of oxygen absorbed is far more than covered by that set free as the result of the decomposition of carbonic acid gas by the action of chlorophyll during the day.

CHAPTER IV.

DIFFERENTIATION. DIVISION OF LABOUR.

We have now studied three simple forms of living beings, and have yet to discuss the question as to whether they belong to the animal or the vegetable world. It will be well, however, to leave this matter in abeyance for a time while we consider the subject of "division of labour" in both animals and plants.

The three organisms dealt with all contain protoplasm, without which life seems to be impossible. Some of the lowest or simplest forms of living beings are mere specks of living protoplasm, exhibiting a perfectly uniform or homogeneous structure—that is, they have no parts of a consistency or appearance differing from the rest. They are described as structureless beings, and the undifferentiated protoplasm of which they are composed has to perform all the vital functions necessary for their existence. It has to digest the food, absorb the nutrient matter, excrete waste products, and absorb the oxygen required. It has also to produce motion, and reproduce its kind.

But in amœba, yeast cells, and protococcus we do observe traces of differentiation in the protoplasm. In amœba we find a nucleus, of denser protoplasm than that which surrounds it, and observe that, when the organism multiplies by division, the nucleus is the first to divide. Also, in amœba, there is a contractile cavity which is probably connected with the function of excretion or removal of waste. In protococcus, too, we find a nucleus; and in the active spores which it produces we observe little cilia of protoplasm that are responsible for locomotion.

Some of the lowest forms of life, which, like the three we have examined, also consist of a single "cell," exhibit a greater amount of differentiation in structure, having portions specially adapted for the performance of certain functions.

When we pass, however, from the "unicellular" beings to those higher in the scale of life, we find that they are masses of cells or units, all resembling more or less the cells of the lowest forms, but that some of them have become modified in such a way that they are able to perform a certain function better than the other cells of the same being.

Thus, in the little freshwater polype (*Hydra*) we find the cells, all somewhat resembling the amœba, arranged in two distinct layers round a tubular cavity. Those of the outer layer are protective (some of them are provided with stinging threads), sensitive, and muscular (capable of contraction); while those of the inner layer are also muscular, and provide the fluid required for the digestion of food. The body-wall of a worm is made up of three distinct layers of cells, the middle one of which is especially concerned with motion and locomotion.

In all the higher plants and animals we meet with accumulations of similar cells, arranged either in layers or masses, and endowed with the power of performing some special duty. Such accumulations of similar cells are termed *tissues*. As examples in plants we may mention the epidermis—a single layer of protective cells that covers the leaves and stems, the soft ground-tissue of the interior of stems, cork, woody tissue, and the glandular tissues that prepare nectar, resin, oil, and various other products of the plant. Among the tissues of animals are the epidermis that protects the softer underlying structures, connective tissue for binding and support, muscular tissue, nerve tissue, etc. Thus we see that the higher plants and animals, all of which at an early stage consist of similar cells only, are made up of a vast number of cells, arranged in layers or masses, each cell being specialised for the performance of some certain function; hence we have a system of division of labour, special sets of cells being set apart for various functions which in the unicellular organism are performed by a single speck of protoplasm.

The higher plants and animals are also made up of very distinct parts called *organs*, each of which is capable of performing a special duty. Thus, in the plant, we have leaves—organs by means of which carbonic acid gas is decomposed and various complex compounds built up, and stamens and pistil—the reproductive organs of the plant. On the animal side we may note as examples the stomach—one of the organs of digestion, the heart—the principal organ of circulation, and the kidneys—which are concerned in the excretion of nitrogenous waste material.

An examination of any one organ will show that it is not composed of one kind of cell only, but that it contains several different tissues. The human stomach, for instance, is lined by a single layer of protective cells, beneath which is a glandular tissue of complicated arrangement for the preparation of digestive juices. Below this again is a thick layer of muscular tissue by which the motions of the contained food is maintained; and, intermingled with all parts there are connective tissues, nerve tissue, and the tissues which form the blood and lymph vessels.

The cells of all living beings contain certain complex compounds consisting of carbon in combination with other elements. These compounds have been built up in living cells, and are termed *organic compounds*, as they are to be found in all organs, but we have already learnt that such compounds are formed in the simplest of living things that possess neither organs nor tissues. Similarly, it is customary to speak of all living beings as *organisms*, whether they contain organs or not.

It will be well at this stage to note the principal differences between organic and inorganic or mineral compounds. We have already seen that the former all contain carbon. On this account they are often spoken of collectively as the carbon compounds, though it must be remembered that many of the latter also contain this element. The most remarkable feature of organic compounds is the small number of elements which they contain. There is an enormous number of such compounds, and the majority of them contain only carbon, hydrogen, and oxygen, or these elements with the addition of nitrogen.

But although the number of elements required to build up organic compounds is so small, it is remarkable that they are often united in the most complex proportions. On the other hand, all the known elements, over seventy in number, are to be found in the various compounds of the mineral world, but the proportion in which they combine is very simple, and the number of atoms required to build up a compound molecule is never very large.

CHAPTER V

DISTINCTION BETWEEN PLANTS AND ANIMALS

We have now to study the principal points of distinction between plants and animals, and to apply the knowledge acquired more particularly to the three unicellular organisms we have examined.

(1) Animals generally feed on matter that is more or less solid, while plants absorb only gaseous food from the atmosphere and soluble matter in the moisture of the soil and atmosphere. There are some few exceptions to this rule, for some of the simplest animals appear to obtain all their nourishment in solution, and parasites belonging to higher forms of animal life derive all their food ready dissolved in the juices of their hosts; but, judging from this standpoint alone, we should be inclined to place amœba in the animal world, and to regard the yeast cell and protococcus as plants.

(2) Animals rarely contain chlorophyll, but the majority of plants contain this substance, which, as we have seen, possesses the power, under the influence of light, of decomposing carbonic acid gas There is, however, one large division of the vegetable world—the *fungi*, of which the mushroom may be taken as a type—in which chlorophyll is absent; and, further, there are a few low forms of animal life that contain a green colouring matter very closely resembling, if not quite identical with, the chlorophyll of green plants. If, then, we finally decide that the yeast cell is a plant, we shall conclude that it is probably allied to the group of fungi.

(3) The cells of animals have generally no definite cell wall, and if some kind of cell wall exists it is not composed of cellulose; but vegetable cells are walled in by cellulose—a substance that chemically resembles starch. It will be remembered that amœba has no cell wall, and that both the yeast cell and protococcus are surrounded by a wall of cellulose.

(4) Animals obtain their carbon from compounds that have already been built up in living beings, but plants obtain this element from the carbonic acid gas contained in the atmosphere and in the water they absorb. It will have been observed that amœba obtains its carbon from the living organisms on which it feeds, while protococcus derives it from the carbonic acid gas dissolved in the surrounding water. But here again we have to note somewhat important exceptions, for the green animals referred to in (2) seem to be able to decompose carbonic acid gas, while fungi and some parasitic plants have the power to obtain their carbon from sources other than this gas.

(5) Animals derive their nitrogen also from complex compounds that have been previously manufactured by living beings, while plants can obtain this element from simple mineral compounds that exist in the moisture of the soil, and, to a small extent, in the air. There are some exceptions to this rule also, especially among the fungi, carnivorous plants and parasitic plants, some of which derive nitrogen from organic sources; but as to the three simple organisms we have studied, we observed that amœba obtains its nitrogen from organic compounds, while the other two can take it from mineral food.

(6) Animals feed on complex food substances which they break up into simpler compounds, but plants feed on simple compounds which they decompose, and then build the elements up into very complex ones.

(7) There are yet other distinctions between plants and animals, though not so important for our present purpose. Among them we may briefly refer to the fact that animals throw off nitrogenous waste material, while plants do not; also that animals exhibit a much greater variety of struc-

ture and function in their cells than do the plants, and this greater variety necessarily denotes a more marked division of labour in the animal than in the plant world.

Now, having considered some of the more important points in which plants and animals differ from each other, it will be interesting to spend a few moments in noting the respects in which they agree:—

(1) Both require food and air, digest the food taken in, and grow by the addition of new substance derived from the food taken.

(2) Although motion is the predominating feature of animal life, yet many plants exhibit movements of different kinds. Some simple plants swim actively in water, as do also the spores of higher forms. Parts of highly-developed plants also move more or less freely, as in the case of young shoots and young roots, the tendrils of climbing plants, the leaves of the sensitive plant, the hairs of the carnivorous sun-dew, and the stamens of several flowers.

(3) Both plants and animals are made up of cells.

(4) Both are produced from an egg-cell which, after fertilisation, increases by division and subdivision.

After studying the above differences between, and resemblances among, plants and animals, and noting the various exceptions given, it will be easily understood that difficulties may arise in the classification of the simplest forms; and it is a fact that, although the higher forms are easily distinguished, some of the lowest living beings resemble one another so closely that it is impossible to state confidently whether they belong to the animal or the vegetable side, or whether they constitute the borderland between the two great kingdoms of living beings, belonging no more to one side than the other.

As regards the three unicellular organisms we have studied, however, there will be little difficulty in deciding to which of the great kingdoms they belong. If we recall the observations made in the earlier part of this section we conclude that—

(1) Amœba is decidedly an animal.

(2) The yeast cell is a plant without chlorophyll, unable to obtain its whole food from the mineral world, capable of thriving without light, and therefore allied to the fungi of which the mushroom is a type.

(3) Protococcus is a plant containing chlorophyll, with the power of decomposing carbonic acid gas under the influence of light, and therefore partakes more of the nature of the green plants.

CHAPTER VI.

STARCH, CHLOROPHYLL, CELLULOSE, ETC.

THE remainder of the present section will be devoted to some observations on a few of the compounds that we have found to exist in the cells of the minute organisms we have examined.

(1) **Starch.**—Scrape the freshly exposed surface of a cut potato very gently with a penknife, put a little of the scrapings on a glass slip, add a drop of water, cover with a cover-glass, and examine under a moderately high power of the microscope. Little pear-shaped granules will be seen floating about in the water, each one exhibiting a number of delicate lines surrounding a point near the small end of the granule, and produced by the arrangement of the substance in layers of different densities (see Fig. 7).

Remove the cover-glass, and add to the specimen a drop of a solution of iodine in water containing potassium iodide, diluted to a pale sherry colour. Replace the cover-glass and examine again. All the granules have now been turned to a blue or violet colour, proving that they consist of starch.

Now cut a very thin slice of potato and pour a few drops of the iodine solution on it. The slice will appear darkly stained, but an examination with a hand lens will show that the whole substance of the potato is not stained blue, this colour being assumed only by the numerous granules of starch that occupy the cells.

Take a small quantity of starch as supplied by the grocer, and mix it with a comparatively large volume of cold water. A milky liquid is produced, but if this is allowed to remain at rest for a short time all the starch will settle to the bottom, leaving a clear liquid above. Hence starch is insoluble in cold water. Add a little iodine solution and shake up the mixture again. The starch now turns blue, as in the case of the starch granules of the potato.

Now apply heat to some of the mixture in a test-tube, agitating it all the time to prevent the starch from settling to the bottom. After a short time the blue colour disappears, the mixture becomes clear and assumes the appearance of a thin jelly. Set aside again for a time, and it will be observed that the starch no longer settles to the bottom, for it is soluble in hot water. The blue colour also reappears as the solution cools, and a gelatinous mass is formed.

The above experiments may be performed with starch obtained direct from a potato by rubbing the two halves of a clean potato together, under a tap from which water is dropping slowly. The water, which is rendered turbid by the starch grains rubbed out, may be collected in a vessel placed underneath.

The presence of abundance of starch in wheat flour also may be proved by putting a little of the flour in a small calico bag, and then kneading it well in a mortar containing water. The starch will pass out through the pores of the calico, leaving in the bag a sticky, nitrogenous substance called gluten, which quickly decomposes in warm weather if kept moist.

(2) **Chlorophyll.**—This, it will be remembered, is the green colouring matter of the protococcus cell, possessing the power, under the influence of light, of decomposing carbonic acid gas.

Put some protococcus cells in a small quantity of alcohol, and let them remain there for some hours. Then note that the alcohol has assumed a green colour. Also examine some of the cells so treated under the microscope, and it will be found that the chlorophyll has all been removed. Thus we learn that this green substance is soluble in alcohol. Repeat the experiment with the leaf of any green plant, and a similar result will be obtained.

Since green plants obtain practically all their carbon from the carbonic acid gas of the atmosphere, we see that chlorophyll is necessary for the production of starch and the other carbon compounds that are formed in their cells. And since the chlorophyll of these plants occurs mainly in the leaves, which present such a large surface to the light of the sun, we naturally conclude that the leaves are the principal organs concerned in the production of the carbon compounds.

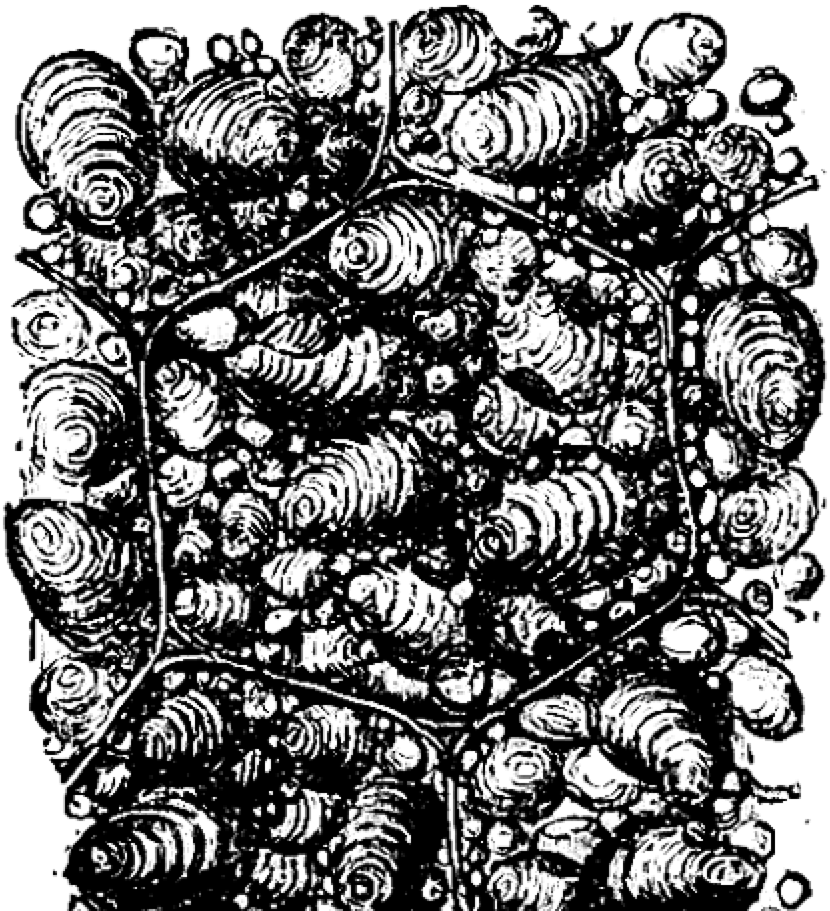

Fig. 7.—Cells of Potato, showing Starch Granules, greatly magnified.

It is interesting to note, too, that chlorophyll itself cannot be formed without light. This fact can be well demonstrated by growing some seedlings in a dark place, when they will remain white. Such seedlings cannot possibly produce healthy plants if this condition be maintained, but, if they be brought out into the light, chlorophyll will soon be formed, and a more healthy condition assumed. An interesting experiment illustrating some of the above facts is described on p. 66.

(3) **Cellulose.**—Cellulose, like starch, contains the elements carbon, hydrogen, and oxygen. It is so called

because it forms the walls of vegetable cells. Cotton is almost pure cellulose.

Cut a very thin section of potato with a razor or very sharp knife—so thin as to contain only a single layer of cells. Press it gently under water to remove the greater number of starch granules contained in the cut cells, and then mount it in water for examination under the microscope. If the section is very thin, most of the cells will be empty, while others, still intact, may be packed with starch granules. Treat the section with a drop of iodine solution and one drop of strong sulphuric acid. The polygonal form of the cells of the potato may now be more distinctly seen, for the cellulose has been stained blue (see Fig. 7).

The above experiment may be repeated with thin sections of fresh elder pith, or of any fresh vegetable substance. Opportunities will thus be afforded of studying the various forms and sizes of plant cells.

A number of other vegetable compounds are formed in plants, mainly by the exposure of the sap to light and air in the leaves. Some of these assist at once in the formation of tissues, while others are stored up until required by the plant.

Among these, sugar and gum are very similar in composition to starch, while vegetable oils, though they contain the same three elements, have a much larger proportion of hydrogen. Legumen, vegetable albumen, and gluten are examples of nitrogenous plant-products.

The non-nitrogenous plant products—starch, sugar, cellulose, gum, oils, etc.—contain only carbon and the elements of water (hydrogen and oxygen), and are built up by the carbon that is derived from the atmospheric carbonic-acid gas, together with hydrogen and oxygen contained in the sap absorbed from the soil.

Starch is rapidly formed in the leaves during exposure to light. Much of this is often changed into sugar, which is then dissolved in the sap, and conveyed to other parts of the plant. Some of the sugar may then be reconverted into starch in the stem or root, where it is stored up for future use.

Nitrogenous plant products, such as protoplasm, legumen, albumen, and gluten, cannot, of course, be formed without the additional presence of nitrogen, and this element is obtained from nitrates and the compounds of ammonium that exist in the soil. The nitrates all contain a metal in combination with nitrogen and oxygen, while the salts of ammonium contain ammonia, which, when free, is a compound gas, consisting of the elements hydrogen and nitrogen, and possessing a very powerful, pungent odour. "Spirits of hartshorn" is a solution of this gas in water.

It will thus be seen that nitrates and the salts of ammonium are important fertilisers of the soil; and when the soil is deficient in nitrogen compounds it becomes necessary to improve it either by adding nitrates or ammonium salts, or by the addition of some kind of organic manure that contains nitrogenous substances. In the latter case ammonia gas is given off during the decomposition of the organic matter, and nitrates may also be formed as the products of decomposition come in contact with mineral ingredients of the soil.

The presence of nitrogen in an organic compound may be proved by mixing it with lime and then warming it in a glass tube, for the lime assists in the decomposition of the organic substance, causing ammonia gas to be set free if nitrogen is present.

QUESTIONS

1. What is a "cell"? Give a brief description of any animal or vegetable cell you have examined.
2. What is a tissue? Give examples of a few animal and vegetable tissues, and briefly describe their uses.
3. Explain what you understand by an organ. Illustrate your explanation with reference to some organs of plants and animals.
4. What is the chemical composition of starch and of sugar? How does their chemical constitution suggest an insight into the way they are formed in nature?
5. What do you know of chlorophyll? What is its use in a plant? By what simple experiment would you demonstrate its use?
6. Whence do plants obtain their supplies of carbon? Illustrate your answer with special reference to yeast and protococcus.
7. What do you know of the composition and occurrence of protoplasm?
8. What are the principal distinguishing features between plants and animals?
9. What are the simplest functions which distinguish living animal matter from inanimate matter?
10. Name the principal nitrogenous compounds formed in plants, and say what you know of the conditions most favourable to their formation.

SECTION II.—PLANT LIFE.

CHAPTER VII.

THE FERN.

External Characters.

We have now to learn something of the higher forms of vegetable life; and, with this object in view, we shall first study a common fern as a type of the flowerless plants, and then deal specially with the main characteristics of the plants that bear flowers.

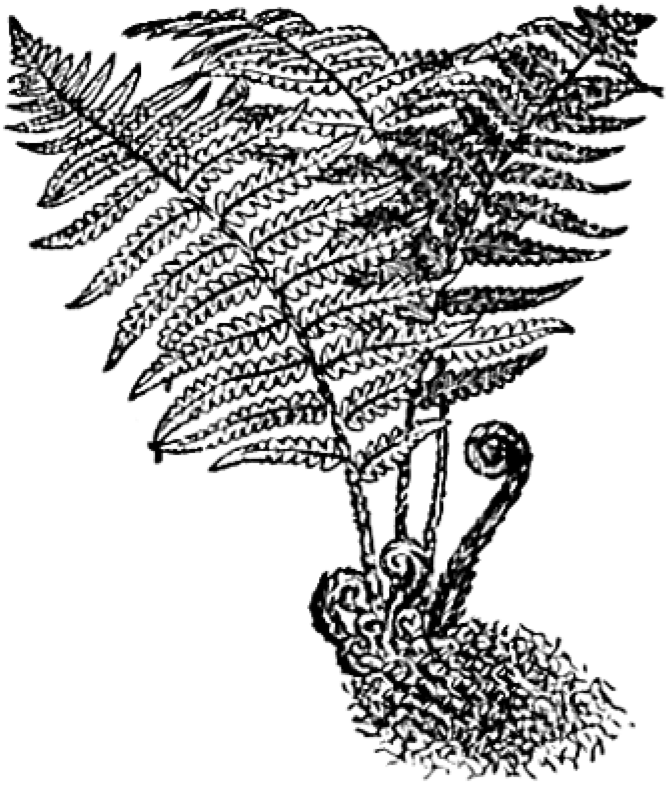

Fig. 8.—The Male Fern.

For the former purpose we shall select the Male Fern (*Aspidium filix-mas*), one of the commonest of British species, which may be found in woods and shady places in nearly all parts of the British Isles; but although our description will be particularly of this species, it must be remembered that the main facts will apply almost equally well to ferns in general; and occasional mention will be made of other common species when important differences are to be noted.

If we dig a male fern out of the soil and examine it, our first observation is that it consists of a thick stem or root-stock, which projects a little out of the ground, with numerous root fibres that grow downwards, and a cluster of beautiful green leaves or fronds on its summit.

Each frond is mounted on a firm footstalk or *petiole*, the lower part of which is covered with shaggy brown scales. It is continued upward through the whole length of the frond, bearing on either side a row of leaflets or *pinnæ*, each row arising from a slight ridge on the side of the petiole. These pinnæ are not arranged opposite each other, but alternately; that is, each pinna is opposite the space between the two nearest pinnæ of the other side.

Examining a single pinna, we find that it is itself divided into still smaller parts, called *pinnules*, the clefts extending almost to the middle line, which is occupied by a central vein. The pinnule is somewhat oblong in shape, with a slightly toothed edge, and fine veins run from the central vein towards the margin, near which each divides into two. Such a disposition of the veins is characteristic of ferns, whether the fronds are divided into pinnæ or whether they are entire, as is the case with the common Hart's-tongue.

When a leaf or frond is divided into smaller wing-like parts it is said to be *pinnate*; and if these parts are again divided into similar portions the leaf is said to be *bi-pinnate*. Thus we may speak of the male fern as having bi-pinnate fronds.

On the under side of a mature frond we may observe numerous little brown patches, of which there is a row on each side of the central vein of each pinnule. These patches are called *sori*, and each consists of a cluster of little bodies (*sporangia*) on short stalks, covered by a rounded or kidney-shaped membrane. In some of the older sori the membrane will be seen to be curved outwards in such a manner as to expose the powdery mass of sporangia beneath it. The sporangia are connected with the reproduction of the

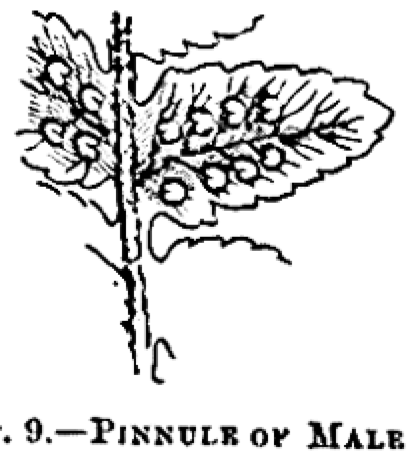

Fig. 9.—Pinnule of Male Fern with Sori.

fern, and will be more minutely examined when we deal with the life-history of the plant.

Pushing aside the fully developed fronds on the top of the stem, we see other fronds that have not yet expanded, all rolled up spirally and covered with thin brown scales. Some, even less developed, hide the summit of the stem. The growth of each frond occupies about three years. During the first year the petiole only is formed. During the second the pinnæ begin to develop, but the whole frond is closely curled into a spiral and completely hidden by the dense covering of brown scales. The expanded frond lasts for one season only, and then dies down to the petiole; but the petiole persists for several years, slowly dying down to its junction with the stem, from which it is finally severed. Thus the stem of the male fern carries the leaves of the present and two succeeding summers, and is also covered below by the bases of the petioles of fronds that existed years before.

Thin brown root-fibres grow downward from all parts of the stem except the summit, and a few may also be seen attached to the bases of some of the petioles. They are freely branched, and the tips of all the fibres, where the new growth takes place, are of a lighter colour than the rest.

We have already noted that the stem is quite hidden by the crown of green fronds and the developing fronds above, and by the bases of the petioles of past years below. On stripping off all these fronds and petioles we observe that the stem is a thick cylindrical mass, without any branches, and usually a little wider towards the top. It stands erect, or nearly so, in the ground, and never reaches a length of more than a few inches; for while additions are made by new growth at the summit every season, the lower part, together with the bases of the older petioles, gradually dies away.

The stems of most ferns grow much in the same way, but many, like that of the common Bracken (*Pteris aquilina*), grow horizontally beneath the surface of the soil. Such creeping underground stems are called *rhizomes*, of which we have many examples among flowering plants as well as among ferns.

INTERNAL STRUCTURE.

Having noted the general external characters of the male fern, we shall now observe the internal structure as far as it can be made out in sections with no further aid than that of a hand lens.

Take a well-developed stem, remove nothing from it save the crown of mature fronds at the summit, and cut it horizontally across the middle. Smooth the cut surface with a very sharp knife or razor. The section (Fig. 10) is very irregular in shape on account of the arrangement of the petioles. It consists mainly of a yellowish ground-substance, in which is an irregular ring of darker spots.

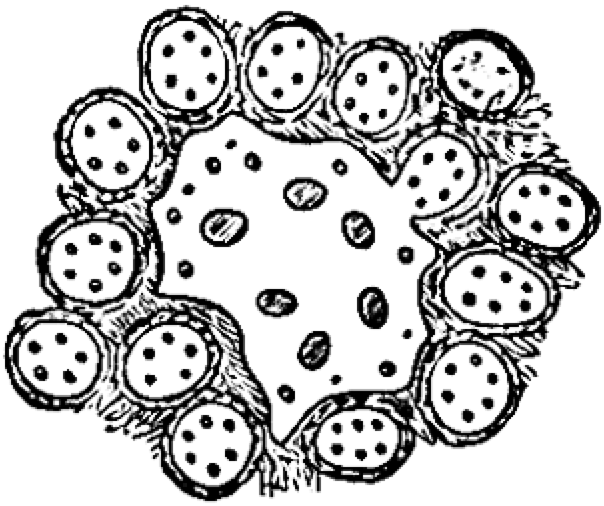

Fig. 10.—TRANSVERSE SECTION OF THE STEM OF THE MALE FERN, SHOWING THE VASCULAR BUNDLES.

The ground-substance is cellular in structure, and is so soft compared with the darker portions of the stem that it may be cleared away from the latter with the tip of a blunt knife. The darker portions are *vascular bundles*—bundles of tissues containing vessels. That portion of the ground-tissue within the ring of bundles is termed the *pith*, while that without is called the *cortex*.

In the cortex are other vascular bundles—outside the ring. These are the *leaf-traces*, which pass from the ring-system to the petioles on their way to the leaves.

Outside the cortex is a rather thick brown rind which is clothed with a dense covering of brown scales.

Now make a vertical section of the stem, cutting from the apex down through the middle. The same stem that was used for the horizontal section may be employed for this purpose if necessary, the upper and lower halves being examined separately.

This section reveals the general cylindrical form of the stem, the petioles, and leaves in various stages of development. Some leaves have the pinnæ well formed, and they are folded into a neat and compact spiral. Others, nearer the apex, are represented by a developing petiole only; and some are mere projections of the tissue of the stem. At the very summit is a slight projection that constitutes the growing point of the stem, for it is here that all forward growth is produced by the division of cells.

The young leaves at first grow perpendicularly from the summit of the stem; but as the latter increases above the surface is displaced, and the petioles eventually make an angle of 60° with the surface, as is seen in the lower portion of the section. The bases of the petioles that have been exposed in the section are also seen to be surrounded with a dense covering of brown scales.

Commencing at the base of the stem, bend back the petioles one by one, snapping them off, and proceed upwards till all have been removed. The majority of the root-fibres still remain attached to the stem, but a few will probably have been removed with the petioles to which they are attached.

A number of scars are now visible on the stem, each one being the area of attachment of a petiole. These are the *leaf scars*, and it will be seen that they are arranged spirally round the stem. Further, after the removal of all the immature leaves on the summit of the stem, together with the covering of brown scales, the projection which marks the growing point of the stem is more easily seen.

In the cut surface we note the same arrangement of ground tissue and vascular bundles previously observed. The bundles forming the ring in the transverse section are not continuous in the longitudinal section; for, as we shall see presently, they do not pass straight up the stem, but form a cylindrical network. In the latter section, however, the leaf traces may be more distinctly seen on their way to the petioles, as well as their connection with the central system of bundles.

Cut off the lower portion of another aspidium stem, and then carefully clear away the pith of the upper part with a blunt knife, being careful not to injure the vascular bundles. The inner surfaces of the bundles will now be exposed, and it will be seen that they form a conical network with lozenge-shaped meshes (Fig. 11), the cone being almost closed at the summit or growing point of the stem. Further, the bundles send no branches into the pith, and each lozenge-shaped mesh is just opposite the origin of a petiole.

The cellular cortex outside the bundle-cone may also be dissected away, but this operation requires much care. It may be conducted much more easily, however, if the stem has been macerated in water for some weeks, since the softer cellular tissue decomposes and breaks asunder more rapidly than the vessels. In the preparation thus made we find that numerous branches pass outwards from the bundle-system. Seven of these branches from each mesh pass to the origin of a petiole, while others run into the root-fibres.

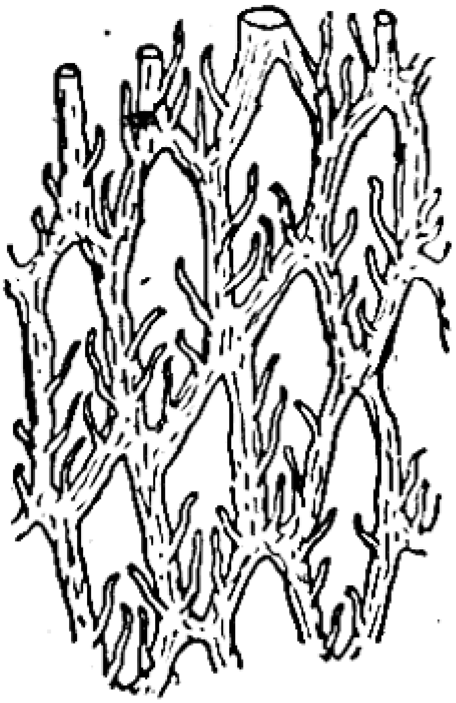
Fig. 11.—Vascular Bundles of the Stem of the Male Fern.

We next make a transverse section of a fresh petiole, using a very sharp knife or razor in order to get a smooth surface. On examining the section with a hand lens we see that the outer cells form a pale brown rind, while almost the whole interior consists of a white ground tissue identical with that of the stem (Fig. 12).

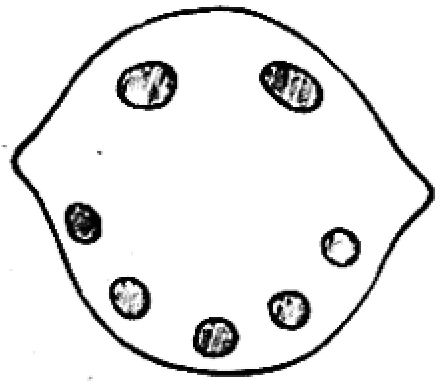
Fig. 12.—Transverse Section of the Petiole of the Male Fern.

In the midst of the ground tissue there are seven vascular bundles, two of them larger than the other five. These originate, as we have already seen, from the bundles enclosing one of the lozenge-shaped meshes of the stem. If we carefully pick away the surrounding ground tissue we find that the five smaller bundles are connected by smaller cross-bundles, while the two larger ones are not so connected. Also, gradually tracing the smaller ones upward through the petiole, we see that the five unite to form three. These give off branches to the pinnæ of the frond, and each branch supplies the smaller branches that we observed in the pinnules, dividing into two as they approach near to the margin.

A root-fibre contains only one vascular bundle, occupying a central position. It may be seen by cutting a transverse section and examining it with a hand lens. If the section be made at the origin of a lateral rootlet a smaller bundle may be seen passing into this rootlet from that in the main fibre. A close examination of the tips of the roots will also enable us to see some young rootlets just breaking through the ground tissue of the main fibres (Fig. 13).

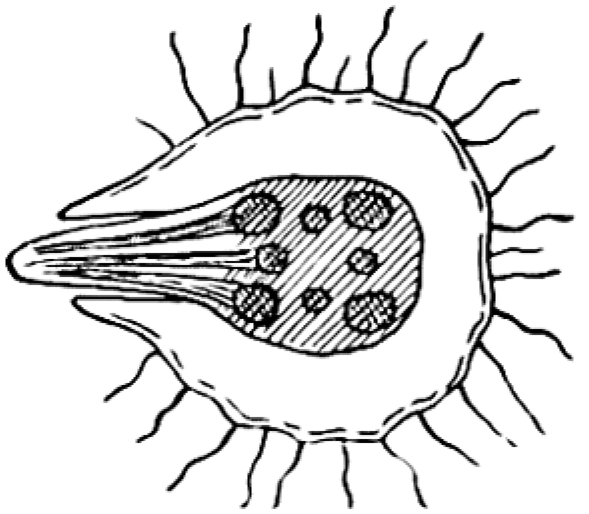

Fig. 13.—Transverse Section of a Root-fibre of the Male Fern, showing the development of a young rootlet.

Microscopic Structure.

Up to the present we have noted the general internal structure of the fern only so far as it can be made out with the unaided eye or with the help of an ordinary hand lens; but it will be interesting now to examine thin sections under the microscope with the object of studying the various forms of the cells and the true nature of a vascular bundle.

The sections made for this purpose must be very thin, and so transparent that the light thrown up by the reflector can pass through them freely. Hold a piece of the petiole firmly between finger and thumb of the left hand, and cut several very thin slices with a sharp razor, keeping both specimen and razor very wet all the time. Allow the sections to fall directly into a small basin containing a little glycerine diluted with about an equal volume of water, for they must on no account be allowed to become dry, or even partially dry.

Select what appears to be the thinnest of the sections, place it on a glass slip, add a drop of the dilute glycerine with a glass rod, and then cover it with a cover-glass.

Even with a low power we shall have only a small portion of the section in the field of view at any one time, but a general examination of the specimen as we bring the various parts into view will show that it is composed entirely of cellular elements. The yellowish outer portion consists of several layers of cells of various forms and sizes. This we have spoken of as the rind. Inside this, and forming by far the greater portion of the section, are the rounded cells of the white ground tissue; and embedded within the latter are the conspicuous vascular bundles, generally of an elliptical form.

Now, starting from the surface and working towards the centre, we note the structure of the section in greater detail as given below:—

At the surface there is a single layer of small cells with thin walls. This constitutes the *epidermis* (Fig. 14), and to it are attached some fragments of the brown scales that clothe the petiole, giving the outline a more or less ragged appearance.

Next to the epidermis are one or two layers of cells with thick yellowish walls; and, inside these, several layers of cells with still thicker walls of a brown colour. All the above cells are polygonal in form, and are so arranged that there are no spaces between them. Together they form the rind of the petiole, which is thus composed of seven or eight layers of cells.

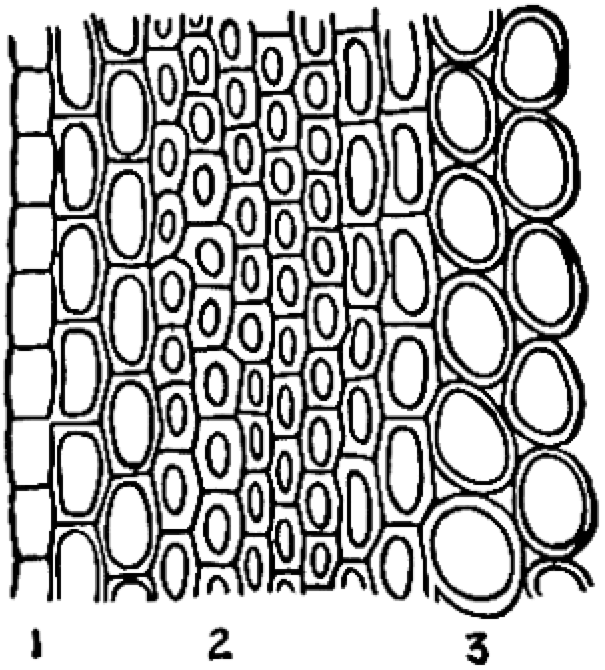

Fig. 14.—STRUCTURE OF THE RIND AND THE GROUND TISSUE OF THE PETIOLE OF THE MALE FERN.

1, Epidermis; 2, Thick-walled Cells of Rind; 3, Ground Tissue.

Inside the rind are the larger cells of the ground tissue. These are not polygonal, but rounded in form, so that little angular spaces (*intercellular spaces*) exist between them. Their walls consist of thin, colourless cellulose, and they contain protoplasm and starch granules. If a drop of iodine solution be added to one of the sections the protoplasm will be stained yellow and the starch granules turned blue. Also, if we apply both iodine solution and sulphuric acid, the cell walls also will be stained blue, thus proving that they are formed of cellulose.

Each vascular bundle (Fig. 15) is enclosed in a thin sheath formed of a single layer of narrow cells joined end to end. These form what is termed the *endodermis*. Inside the sheath are layers of angular cells, with thin colourless walls, containing protoplasm and starch. Next is an irregular ring of cells, more or less modified, together forming the *bast* or *phloëm*. It includes bast fibres, composed of elongated cells with thin colourless walls, and *sieve-tubes*, which consist of long cells, the end walls of which are perforated. The bast fibres and sieve-tubes are bound together by cells resembling those of the ground tissue.

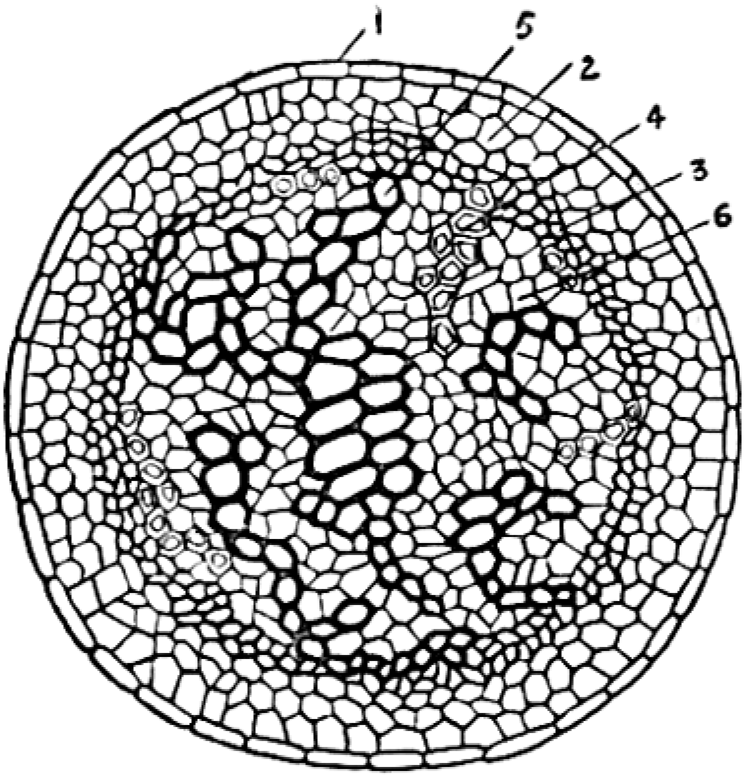

Fig. 15.—A **Vascular Bundle.**

1, Endodermis; 2. Cells containing starch; 3, 4, Bast; 5, Wood; 6, Ground Tissue.

The central portion of the bundle is occupied by *wood* or *xylem*, which consists principally of fibres larger than those of the bast, with very thick walls. They have been formed by elongated cells, placed end to end, in which the transverse partitions have partially broken down. The walls are of a yellow colour, and have become very angular by mutual pressure. The thickening of the walls has not been uniform, so that they exhibit numerous depressions that mark the thin places; hence they are termed *pitted vessels.* The protoplasm has disappeared from the wood fibres, and they contain only water or air; but among them are some ground-tissue cells with both protoplasm and starch.

The pinnæ of the frond of a fern are covered with an exceedingly thin layer of *epidermis*, the cells of which generally contain no chlorophyll, so that the epidermis is colourless. A small piece of this epidermis may be removed with the point of a knife, or it may sometimes be seen projecting from the edge of a torn pinna. If a piece of the epidermis that has been removed from a pinna appears of a greenish colour it may be known that some of the underlying tissue, with chlorophyll granules, is attached to it. With a little care, however, we may obtain a fragment of epidermis quite free from other tissue; and we place this in a drop of water for microscopic examination.

If the epidermis be from the upper surface of a pinna it will be seen to consist of very thin cells of a comparatively large size, with irregular sinuous outlines, and joined together at their edges without any intervening spaces. All the cells are similar in nature, and none contain chlorophyll.

Epidermis removed from the under side of the frond is made up of two very distinct kinds of cells (Fig. 16). One kind corresponds exactly with those of the upper surface, but the others are of a very different nature. The latter are smaller, of a crescentic form, and contain chlorophyll granules. They are always arranged in pairs, with their ends in contact and their concave sides towards each other. Thus there is always a space between the cells of each pair, though this space may vary much in size under different circumstances. These cells are called *guard-cells*, and the spaces enclosed by them are the *stomata*.

The internal structure of a frond may be studied best from a transverse section of one of the pinnules. To prepare such a section it will be necessary to imbed the pinnule in elder pith, carrot, or some other soft cellular substance. Cut a slit in a small piece of carrot and pass a pinnule into it vertically; then cut away the thinnest possible slices of both carrot and pinnule with a sharp razor, keeping both razor and material wet, and allow the slices to fall into a vessel of water. Select the thinnest section of the pinnule, transfer it to a glass slip with a needle, add a drop of water, and cover with a cover-glass. The section, if sufficiently thin, should be transparent, and show the cellular structure clearly under the microscope. Starting with the upper surface (Fig. 17), we observe a single layer of thin cells, with no intervening spaces and no chlorophyll. These form the upper epidermis. Below this are cells of larger size, packed closely together, and containing numerous chlorophyll granules. Towards the lower surface we find similar cells, but more irregular in form, and enclosing a number of air-spaces. Then, forming the lower surface of the pinnule, is another layer of colourless epidermal cells, with small openings (*stomata*) here and there, each having a chlorophyll-bearing guard-cell on either side. It will also be observed that each stoma forms an opening into one of the air-spaces of the spongy tissue of the lower half of the section.

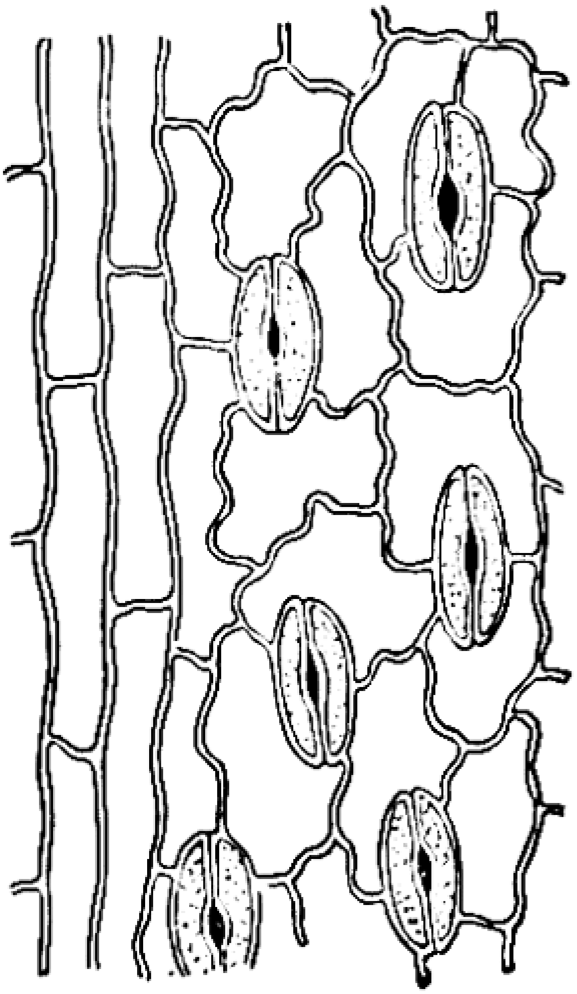
Fig. 16.—Epidermis of the Frond of the Fern, Magnified.

In addition to the structures just mentioned we may also see in the preparation one or more sections of the vascular bundles that form the veins of the pinnule. These will bear a certain resemblance to the larger bundles of the petiole and stem, each having a surrounding sheath, and containing both wood and bast.

If we now cut off the tip of a pinnule, and mount it in a drop of water, we shall find that, with proper focussing, the cells at different depths may be seen fairly well, the pinnule being sufficiently transparent for this purpose. And if we apply pressure on the cover-glass by means of a needle, small bubbles of air will be seen to issue from the cut edge, thus showing that the air-spaces of the spongy tissue communicate with each other.

We next return to the root of the male fern, and carefully select a root-fibre that is quite uninjured at the tip. This we mount in a drop of water and examine under a low power. The end of the fibre is now seen to be covered by a cap (*root-cap*) of cellular structure. The use of this is to protect the tip of the fibre as it pushes itself forward in the soil. The outer cells are continually being worn away by friction, but new cells are always being formed to take their place. Thus the growing point of the root is not *quite* at the tip, but is covered by the root-cap. (See Fig. 26.)

There is often some difficulty in securing uninjured roots, since the tender tips of the fibres are generally torn off or damaged as the plant is removed from the soil; but perfect specimens of root-caps may be readily obtained from aquatic plants the roots of which either penetrate very soft mud or are suspended freely in the water. Thus, if the reader experiences any difficulty in finding a perfect root-cap of the male fern, he will do well to examine the similar structure at the tip of the root of the common duckweed, which may be found floating on the surface of almost every pond.

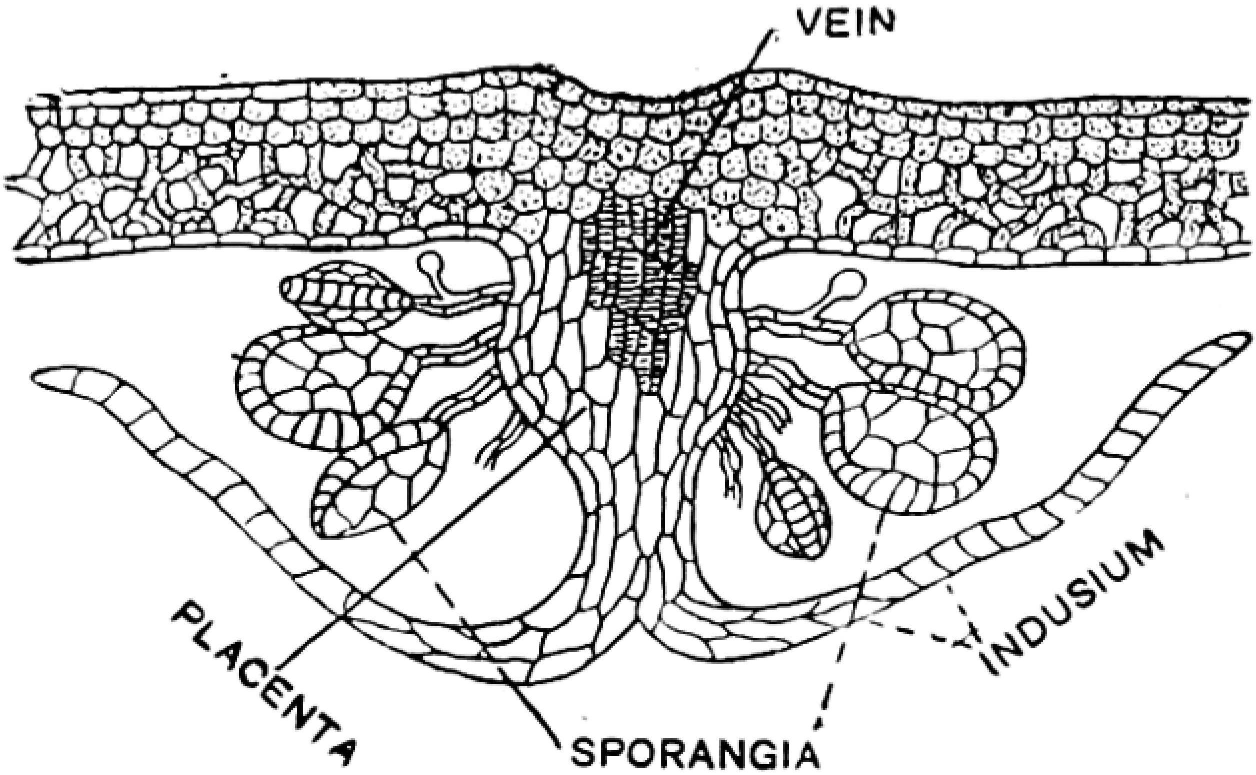

Fig. 17.—Sporangia of Aspidium.
Transverse section through a pinnule and sorus.

A thin transverse section of the root of a fern may be easily cut with a razor if the specimen be secured in a piece of pith or carrot as already described. Such a section will reveal the following structures:—

Externally there is an *epidermis*, composed of a single layer of brown-walled cells, with root-hairs, each of which consists of a single elongated cell with a very thin wall. Next to this is the *ground tissue*, composed of cells with thin pitted walls. In the centre of the fibre is a single *vascular bundle*, with thick-walled woody fibres in the middle, partially surrounded by bast, both wood and bast being imbedded in ground tissue. The whole is enclosed in a sheath of narrow thin-walled cells, arranged end to end in a single layer, with several layers of thick-walled cells outside. Thus we see that the vascular bundle of a root-fibre consists of the same elements as the bundle of a petiole, but with a different arrangement.

A longitudinal section cut through the middle of the extreme tip of the fibre will show the protective cells of the *root-cap*, together with the *growing point*, where all new growth is produced by the division of an *apical* or *terminal cell*, situated immediately beneath the cap. (See Fig. 26.)

We have now seen that the stem, petiole, frond, and root of the fern all consist of a variety of cells, differing considerably both in form and structure, and all adapted to the performance of certain definite functions:—protective epidermal cells at the surface; guard-cells to regulate the size of the stomata through which air and water-vapour pass; ground-tissue cells to connect various parts, with cell-walls so thin that fluids can readily diffuse through them; cells with thickened walls to give strength to the parts; and elongated cells forming fibres that give toughness to the organs or form vessels for the conveyance of the sap.

Although we have such a variety of cells, all more or less specialised for the performance of certain functions, we must remember that each individual element was originally a cell somewhat resembling the protococcus, with a thin wall of cellulose, and containing protoplasm and a nucleus. Some of these have undergone considerable changes in form, and in many the wall has become thickened, either uniformly or locally, by the formation of new cellulose or an allied substance. In certain cases the protoplasm has entirely disappeared, and the cells contain nothing but air or sap, while in other instances, more particularly in the leaves, chlorophyll, starch, and other vegetable products have been built up by the energy of the sun's rays.

REPRODUCTION.

We have already noticed that the fern bears no flowers. Flowering plants produce seeds, each of which contains an embryo plant, ready to develop as soon as favourable conditions arise. Ferns are flowerless plants, incapable of producing seeds, but they give rise to minute cellular bodies called spores. The spores do not contain embryo ferns, but they have the power of producing little plant bodies from which ferns may be afterwards developed. We have now to trace the interesting life-history of the fern, first endeavouring to learn the true nature of a spore, and then watching the development of the plant through a complete cycle from spore to spore.

If we carefully examine one of the brown patches (*sori*) that we have already observed on the under side of a mature frond, we find that, as a rule, nothing is visible save a small brown umbrella-shaped membrane (the *indusium*). Lifting one side of this with a needle-point, we observe, with the aid of a good lens, that it is attached to a little globular mass of cellular tissue (*placenta*), which also gives rise to little brown bodies (*sporangia*) on short stalks. (See Fig. 17.)

A few of the sporangia may be transferred to a glass slip, and examined in the dry state under the low power of a microscope, allowing a good light to fall on them from above. Each sporangium is a minute pouch, with a rim of thick-walled cells extending from the stalk over the top. During an early stage of the sporangium it consists of a double envelope enclosing a single cell. This cell afterwards divides, usually into sixteen cells (mother cells), and these again divide into four, thus forming a total of sixty-four. At last, when the sporangium is quite mature, the thickened rim contracts in dry weather, thus tearing it open, and setting free the sixty-four cells, which are termed *spores*. Each of these minute spores is capable of producing a fern plant, but it differs from the seed of a flowering plant in that it is a single cell, and does not contain the young plant in an embryonic stage.

Now procure the mature frond of a fern that bears sori, and keep it in a dry atmosphere for a few days. Many of the sporangia will now have been ruptured by the contraction of the thickened rim, and a large number of spores may be obtained by beating the frond on a large sheet of white paper. Also obtain a flower-pot saucer with a hole in the bottom, and half fill it with peat. Press the peat down firmly so that it has a smooth surface, moisten it well, and sow some of the spores on it. Further, obtain a sheet of glass large enough to cover the saucer, moisten the middle of one side and dust the moist surface with spores. Put this glass, spores downward, over the saucer, and set the whole aside for observation out of the direct rays of the sun. The spores will now germinate, thus giving a splendid opportunity of observing the early stages in the development of the fern. Both the peat and the glass should be examined from day to day with a lens, and the student should make a series of sketches recording the various stages of development. The earliest of these stages may be studied best by observing those spores that germinate in the drops of water which form on the under surface of the glass.

At first the cell-wall bursts, and the contained protoplasm protrudes through the rupture. New cells are then formed by the transverse division of the protoplasm until a little filament, consisting of three or four cells, is formed (Fig. 18, A). A little unicellular root-hair (*rhizoid*) is also formed, and this grows downward, penetrating into the soil. New cells are then formed at the tip of the filament, and these divide longitudinally as well as transversely (Fig. 18, B), thus giving rise to a flat leaf-like expansion, which afterwards becomes heart-shaped, and reaches a length of about one-third of an inch (Fig. 18, C).

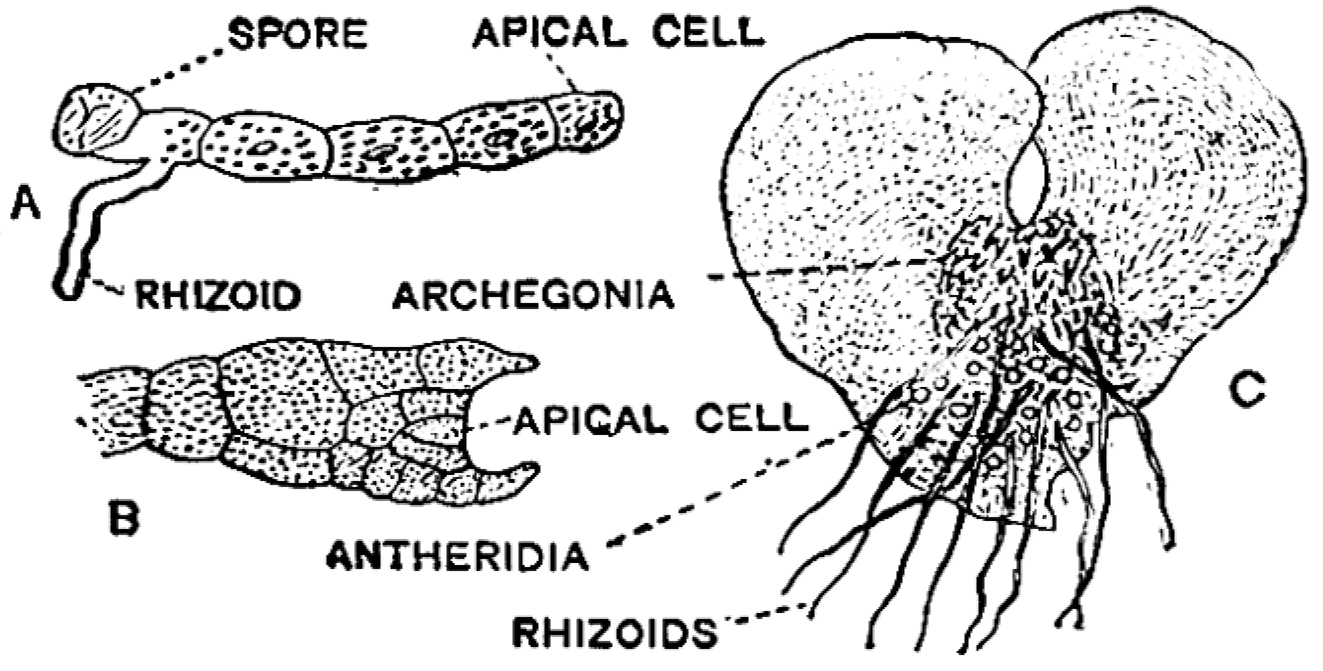

Fig. 18.—Germination of Spore and Development of Prothallus of Fern.

The little plant thus formed is called a *prothallus*. It does not grow into a fern, nor does it further increase in size. It is in all respects an independent plant. Its cells contain chlorophyll granules, which enable it to decompose carbonic acid gas. It has no stomata, nor does it require any, for it is so thin that gases can readily penetrate into the interior of its substance. Numerous root-hairs develop on the under surface, and these, penetrating into the soil, give attachment to the plant, and also absorb dissolved food.

The margin of the prothallus is very thin, consisting of a single layer of cells, but the central portion becomes thickened by the division of cells parallel to the surface. The thickened portion is termed the *cushion*.

Little rounded bodies are developed on the under side of the prothallus by the division and outgrowth of its cells. These are the sexual organs of the plant, and are of two kinds—the *antheridia* or male organs, and the *archegonia* or female organs.

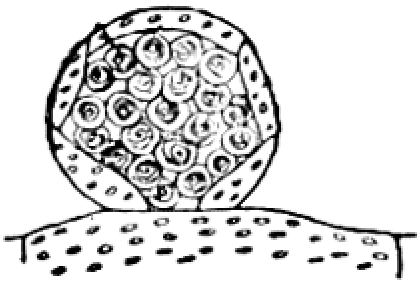

Fig. 19.—Male Organ of Fern.

The male organs are the smaller, and are formed principally at the apex of the heart-shaped prothallus, though they may occur on any part of the under surface. They are also developed earlier than the female organs. Inside each male organ are a number of small cells, each of which gives rise to a male cell (*spermatozoid*)—a minute body with a small nucleated head and a slender spiral tail. The tail bears a number of delicate hair-like projections called *cilia*, which are capable of vibrating rapidly and propelling the cell through water.

The female organs are more cylindrical in form, are produced later, and are situated on the cushion, close to the notch of the heart-shaped prothallus. The wall of the organ consists of a single layer of cells, and within at the bottom an egg-cell or *ovum* is formed. A canal leads from the egg-cell to the summit of the organ.

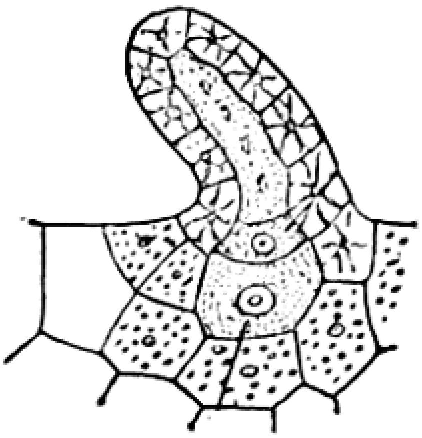

Fig. 20.—Female Organ of Fern.

When the male organs are mature, the little male cells are set free. The cells are then propelled through the moisture on the under surface of the prothallus by their ciliated tails. They are attracted towards the female organs, and when a male cell reaches the female organ it enters the canal, and passes down to the egg-cell, with which its nucleus fuses. The egg-cell is thus *impregnated*, and, as a result, it divides into eight cells. Two of these cells develop into the stem of the future fern, another two give rise to the frond, two form the root, and the remaining two develop into a foot by means of which the young fern remains for a time attached to the prothallus. Thus, by a continued process of cell division, the parts of the future fern are gradually developed. The foot becomes thick, and absorbs nourishment from the prothallus until the fern is so far advanced that it can obtain food for itself, and then the prothallus, having completed its work, dies, leaving the young fern to absorb mineral food from the soil by its own roots, and to decompose carbonic acid gas by the chlorophyll granules of the cells of its still tiny frond.

It will be seen from the above description that while each fern is capable of producing an enormous number of spores, and, therefore, a large number of prothalli, each ovum or egg can produce but a single fern.

In the life-history of the fern we have an example of *alternation of generations,* the reproductive bodies formed by one generation giving rise to the other. The spores of the fern are produced without the aid of any sexual organs, and these spores give rise to a prothallus which bears the sexual organs that produce the fern.

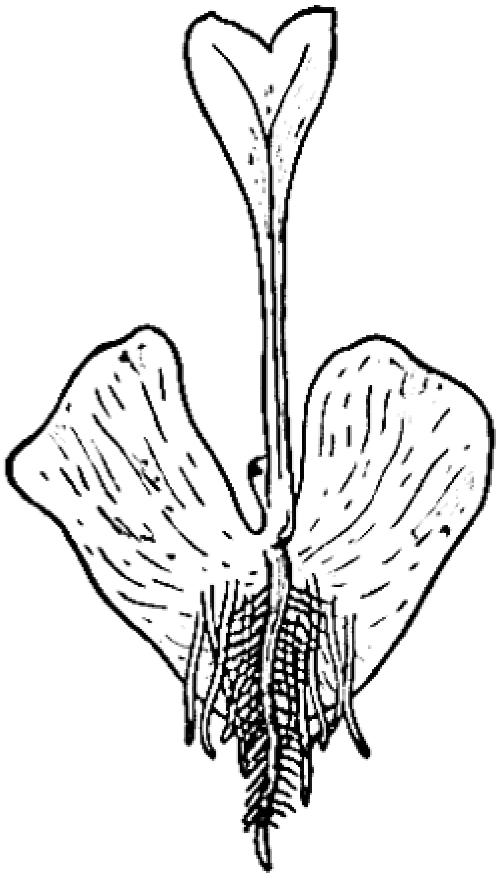

Fig. 21.—YOUNG FERN STILL ATTACHED TO THE PROTHALLUS.

When the male cell fuses with the egg-cell the latter is said to be impregnated or fertilised, and it will have been noticed that the latter cannot as a rule be self-fertilised—that is, fertilised by male cells belonging to the same prothallus—for the male cells are developed earlier than the egg-cells. Thus the ova must as a rule be fertilised by cells from a neighbouring prothallus. Such a process is termed "cross fertilisation."

The first leaf of a young fern is small and very imperfect, and several are produced in succession before the size and form of the mature frond have been attained.

QUESTIONS.

1. Give a general description of the parts of a fern, and state briefly the function of each part.

2. Describe the leaf or frond of any fern you have examined, and give an account of the changes in appearance during the period of its growth.

3. Describe the external characters of the stem of a fern.

4. Describe the structure of the stem of a fern as far as it can be made out by examining sections without the aid of a microscope.

5. What is a vascular bundle? Of what does it consist, and what is its use to the plant?

6. Describe the structure of the epidermis of the frond of a fern. Describe the different kinds of cells that compose it, and state their functions.

7. What food materials are derived (1) from the soil, and (2) from the air by a fern plant? In what form and through what structures are these materials absorbed?

8. Describe the nature and function of the brown patches that may be seen on the surface of a mature frond.

9. What is a spore? Give a brief description of the manner in which it germinates.

10. What are the green scale-like bodies so frequently seen growing on moist surfaces in a fernery? How are they produced, and to what structures do they give rise?

11. Explain what is meant by the expression "alternation of generations."

CHAPTER VIII.

THE FLOWERING PLANT:

ILLUSTRATED PRINCIPALLY BY THE FIELD BEAN.

THE GROWTH OF A PLANT.

WE have now to study the general structure of a flowering plant, and the mode of growth, structure, and function of its various parts. The Common Field Bean (*Vicia faba*), also known as the Horse Bean from the fact that it is largely used to feed horses, will be chosen as our principal type, but continual reference will be made to other flowering plants with the object of studying their varying habits and their adaptations of structure to these habits. Where circumstances permit it is advisable to commence this portion of our work in the spring season.

Sow some field beans in a box of sawdust, and keep them well watered. Also sow a cluster in soil in the open, as well as a few several inches apart that are to be allowed to reach the flowering and fruiting stages.

As soon as the young plants have developed a few pairs of leaves remove one carefully from the soil and examine its various parts. In it we readily distinguish four distinct parts—(1) The root or descending axis which grows downward into the soil, (2) the stem or ascending axis that grows upward from the soil, (3) leaves growing out from the stem in pairs, and (4) a bud at the summit from which new leaves and other organs may be formed.

Sow some beans in soil contained in two separate flower-pots or boxes. Keep both well watered, and, as far as possible, at the same temperature; but place one in a perfectly dark cupboard or cellar, and leave the other exposed to full light. Enter in a note-book the date of sowing, and the *average* height of the seedlings at the end of each week. At the end of each week remove an equal number (about three or four) of the seedlings from each pot or box, wash the roots in running water, and then dry them thoroughly, in two separate lots, in an oven surrounded by boiling water. (They should not be raised to a temperature higher than that of boiling water.) When thoroughly deprived of all their moisture, and thus rendered hard and brittle, weigh each lot separately, and, dividing by the number of plants in each lot, obtain the average weight of the solid material in each individual plant.

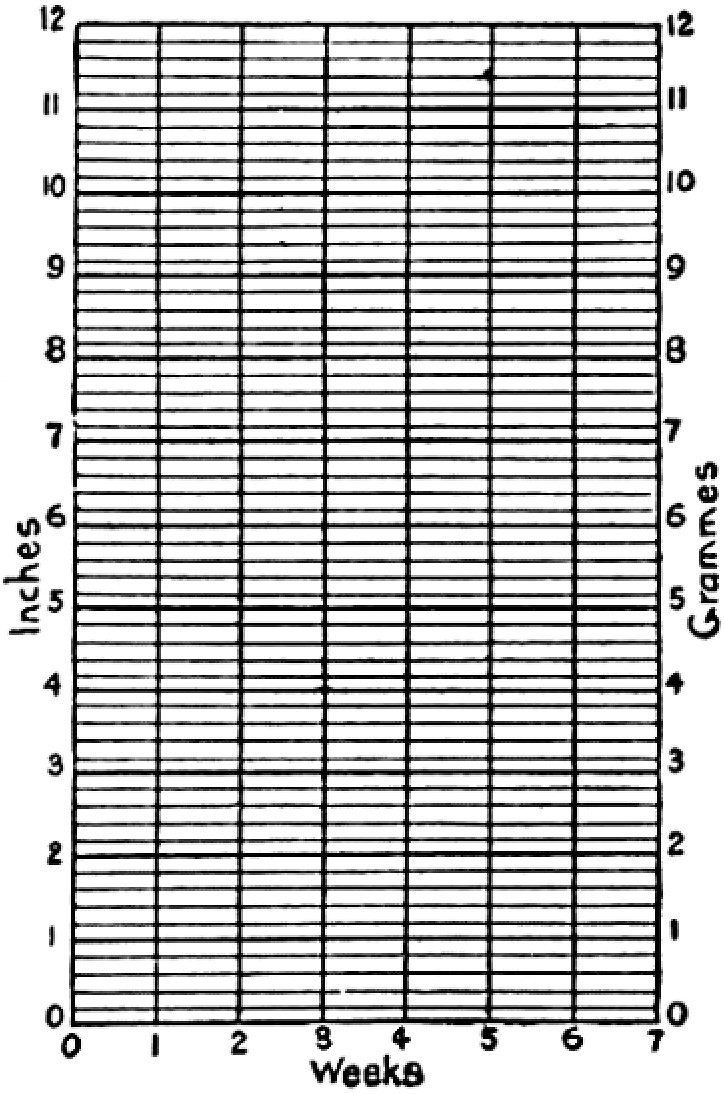

Fig. 22.—Chart on which to plot the curves of height and weight.

Now obtain a piece of squared paper, divided either into millimetres or inches and tenths of inches. Mark out on this a rectangular space, and divide it by vertical lines into spaces (seven or eight) representing weeks. On the left side of the rectangle, commencing at the bottom, mark off equal spaces to represent inches and fractions of inches (the space *representing* an inch need not necessarily be an inch), up to twelve or eighteen in number. Also, divide the right side of the rectangle into about as many parts representing grammes and fractions of grammes. As the weekly observations proceed, trace two lines across this paper, starting both from a "zero" at the bottom left corner, these lines or "curves" to show, one the height, and the other the weight, of the normally-grown seedling at the end of each week. Two other lines, dotted or in red ink, starting from the same zero, are drawn to show the height and weight respectively of the seedlings grown in darkness.

Thus we are enabled to compare the growth of seedlings under the two conditions named, and the result shows that while the plant grown in darkness grows more rapidly in height on account of its struggle to reach the light, this same plant does not produce so much solid material as the one grown in light.

Sow some more beans in two separate pots of sand that has been previously thoroughly washed in running water. Keep both under the same conditions as regards temperature and light. Also keep both regularly watered, but use plain water in one case, and a specially prepared nutritive solution in the other Such a solution may be made by dissolving together some mineral salts containing the elements that plants require, and the following answers all purposes:—

Nutritive Solution for Plants.

Potassium nitrate (nitre)	1	gramme.
Sodium chloride (common salt)	½	,,
Calcium sulphate	½	,,
Magnesium sulphate (Epsom salt)	½	,,
Calcium phosphate	½	,,

Add the above to about a litre of water, and then pour in a few drops of a weak solution of iron chloride.

Compare the growth of the two sets of seedlings, and note that those watered with the nutritive solution grow faster and stronger than those supplied only with plain water. It will, of course, be understood that the washed sand, being quite insoluble, can supply no mineral matter to the plants.

Sow a bean (or other seed) in a flower-pot of soil, and support the pot in such a manner that it inclines towards a window at an angle of about 45°. Watch the progress of the seedling, and note that the ascending axis or stem does not maintain a direction at right angles to the surface of the soil, but shows a decided tendency to rise vertically.

At the same time the younger portion of the stem bends somewhat sharply towards the light (Fig. 23).

Most stems have this tendency to grow in an upward direction, even though they grow in the dark, and hence the tendency must be due to the action of gravity; but at the same time it is clear that they are also influenced by light. Some stems naturally grow horizontally, and thus show that they are not influenced in this way by either gravity or light.

If now we remove the plant from the soil and examine its root, we find that the main axis descends, evidently also one of the effects of gravity. The lateral rootlets, however, generally show a tendency to grow horizontally. The lateral rootlets are influenced also by the nature of the soil, always extending themselves more rapidly in the direction of increased moisture and greater abundance of food material.

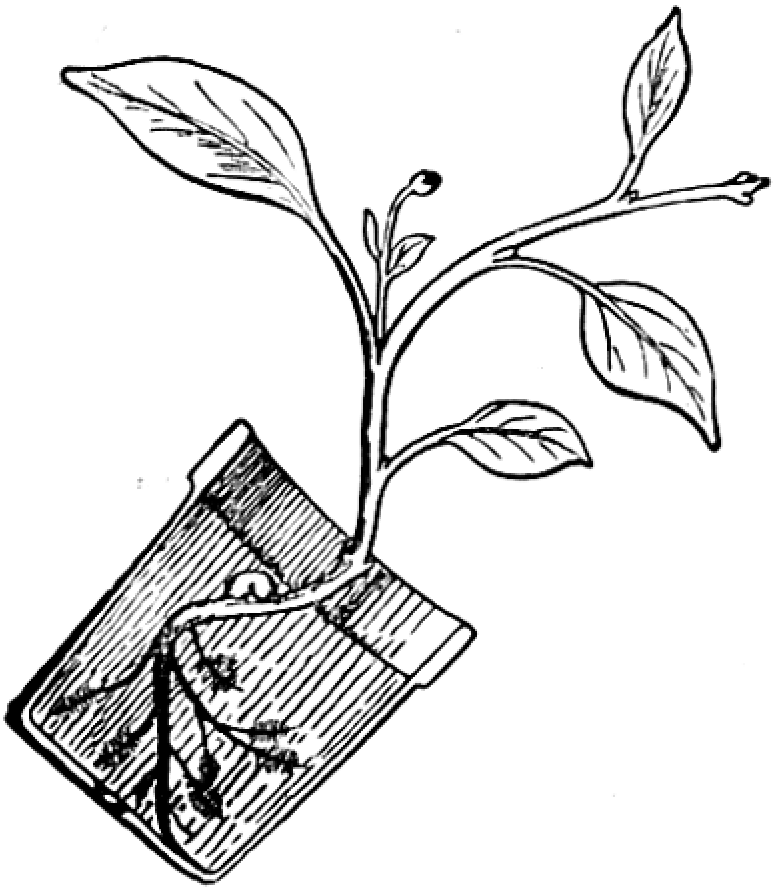

Fig. 23.—A Seedling grown in an inclined pot and illuminated from the right side.

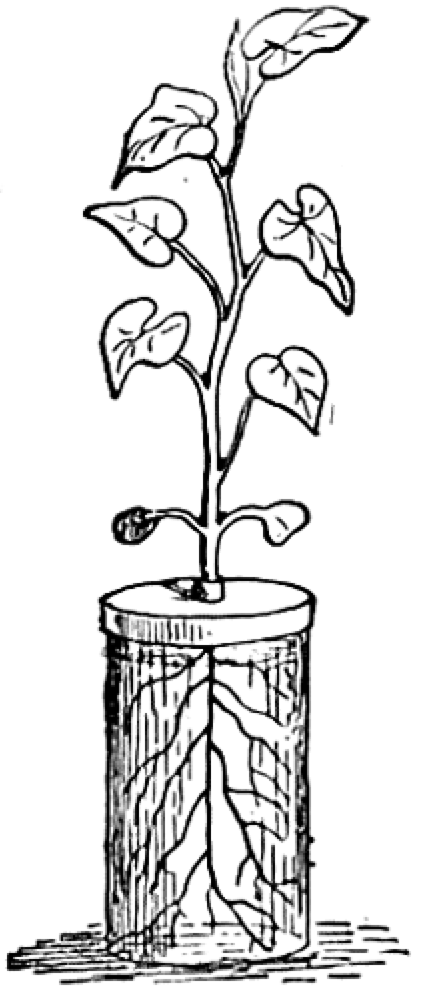

Fig. 24.—A Plant of Buckwheat grown with its Roots in a culture-solution.

As a further illustration of the value of mineral matter to a growing plant take two seedlings of the bean (or other plant), of the same age and size, and support them in separate vessels as shown in our illustration (Fig. 24). Supply one with plain water only, and the other with the nutritive solution recommended. Note that the former soon sickens, and eventually dies, while the latter grows as vigorously and healthily as if allowed to remain in the soil.

The Root.

Wash the soil from the root of a bean plant gently by means of running water, and examine it in all its parts carefully, first with the naked eye and afterwards with the aid of a lens. Note the general form and mode of branching, and make a sketch of the whole root exactly the natural size.

Note, here and there, little wart-like swellings or *tubercles*. These are characteristic of the roots of peas, beans, and allied plants. They contain very minute organisms called *Bacteria*, visible only when very highly magnified; and these organisms are a means by which the plant is enabled to use nitrogen direct from the atmosphere. Most plants can derive their nitrogen only from mineral compounds that are dissolved in the soil, but the presence of the bacteria in the roots of the above-mentioned plants enables them to thrive in poor sandy soils that contain but a scanty supply of mineral food.

Observe also that the root consists of a main portion or *axis* from which branches (*rootlets*) arise in four vertical rows.

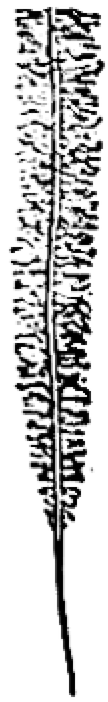

Fig. 25. Rootlet with Root-hairs, Magnified.

At the end of the rootlets are the young and soft portions which must now be examined very carefully with the aid of a hand lens. Here we find very minute *root-hairs*, to which small particles of soil may still adhere. Root-hairs previously existed on the older parts of the root, but they disappear as the root grows, while new hairs are continually being formed at the young extremities of the rootlets. They are outgrowths of the superficial cells of the rootlet, and their function is to absorb liquid food, which readily penetrates their exceedingly thin cellulose walls.

It is possible that many of the root-hairs have been damaged by the removal of the plant from the soil, and a more perfect specimen may generally be obtained from those grown in sawdust. In one of these plants note also the delicate cap (*root-cap*) that surrounds the extremity of each rootlet. It consists of several layers of cells, being thickest at the extremity, and extends some little distance along the sides, fitting on the extremity somewhat like a thimble on a finger, and generally terminating abruptly with a distinct rim.

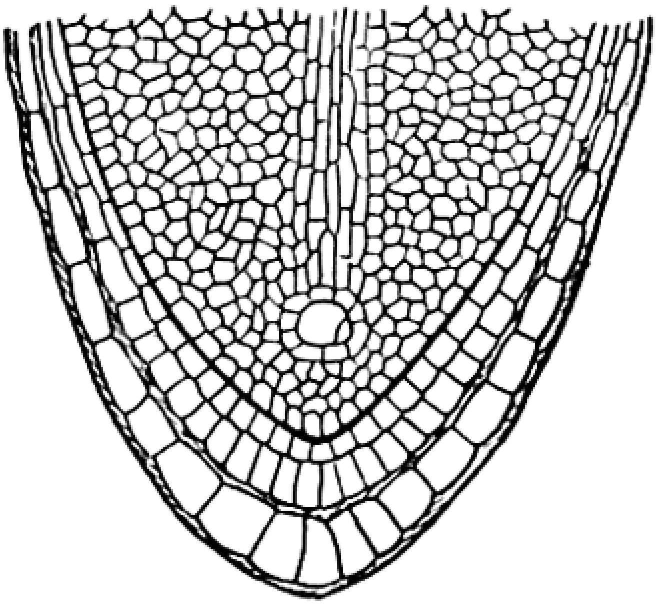

Fig. 26.—THE ROOT-CAP, IN SECTION, MAGNIFIED.

The large cell near the apex of the fibre represents the growing-point.

The nature of the root-cap may be observed very much better in the little plant called the duckweed, which may be found floating on the surface of almost every pond; and we strongly advise the reader to examine and sketch it as seen in one of these plants. The cap serves to protect the delicate extremities of the rootlets as they push their way through the soil, and new cells are being continually added to it from beneath as the surface cells are worn away. It will be interesting for the student to note, however, that the duckweed possesses a root-cap even though its roots grow freely in the water and are consequently in but little danger of receiving injury through friction.

Cut through the thickest part of the root transversely with a very sharp knife, and examine the section with a lens. Note that there is no evidence of the presence of chlorophyll in any part. Note also the fibro-vascular bundle in the *centre* of the root. Make another transverse section at a point where a rootlet branches from the main axis, and observe that the rootlet grows outward from the centre of the root.

Finally, note that the root has no buds, and that it bears no appendages in any way comparable with leaves.

Let us now examine the roots of several other plants in order to see how they differ in form and function. We have already observed that the root of the bean bears no leaves or buds, but the roots of some plants and trees *are* able to produce buds that develop into leaf-bearing stems. This is the case with the hawthorn, poplar, and lilac. Again, roots generally grow downward into the soil, but the ivy and other plants bear little *aerial roots* on their stems. Those of the ivy are commonly spoken of as *suckers*, and they attach the plant to the surface up which it climbs.

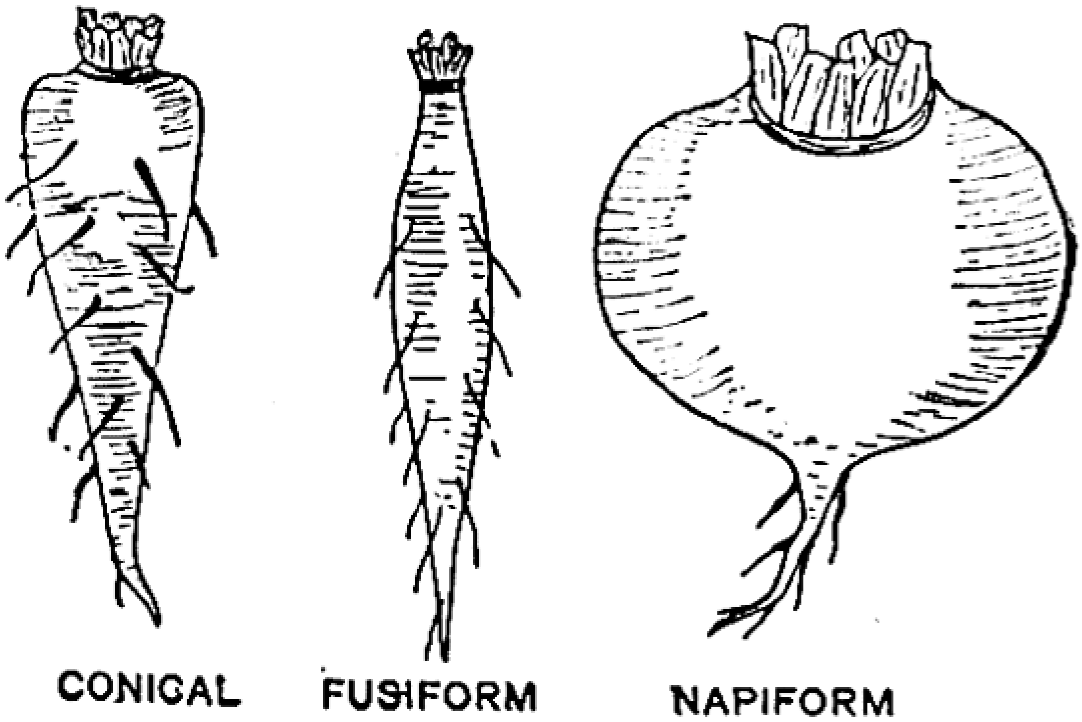

Fig. 27.—Forms of Thickened Tap-Root.

Roots are greatly influenced by the soil in which they grow; thus, in a dry soil they are tough and stringy, while in moist ground they are usually swollen and more succulent. Many plants form very large succulent roots in which a store of food material is held in reserve. Such is the case with the conical tap-root of the carrot and parsnip, the fusiform tap-roots of the radish and beet, and the napiform tap-root of the turnip, each of which stores up nourishment during the first year of the growth of the plant, to be consumed in the following season in the formation of the flowers and fruit.

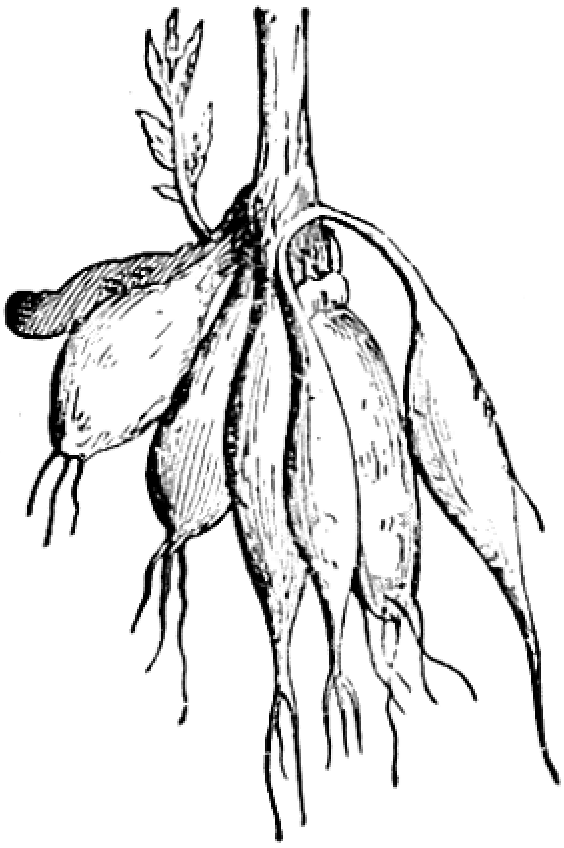
Fig. 28.—Tuberous Roots of the Dahlia.

Some plants send their fibrous roots deep into the subsoil for the necessary food, while others are surface-feeders, distributing their root-fibres horizontally just beneath the surface of the soil. Plants of both kinds may therefore grow together without any disadvantage to either.

Many plants produce extra (*adventitious*) roots in addition to those formed normally. The aerial roots of the ivy are of this kind; so are the very long fibrous roots of the barley and other grasses. That of the barley is often more than a yard in length; it is therefore capable of collecting food from soil far beyond the reach of the ordinary roots. Other examples are to be found in the tuberous roots of the orchid, dahlia, and pæony, all of which serve for the storage of reserve food materials (starch, sugar, etc.) for the development of new plants in the following season.

Still one other kind of root must be referred to, namely that of the mistletoe. This plant is a parasite, deriving its food from the sap of the hawthorn, apple, or oak tree to which its seed happens to be carried by the agency of birds. Its roots penetrate the wood of its host, from which it derives all its mineral food.

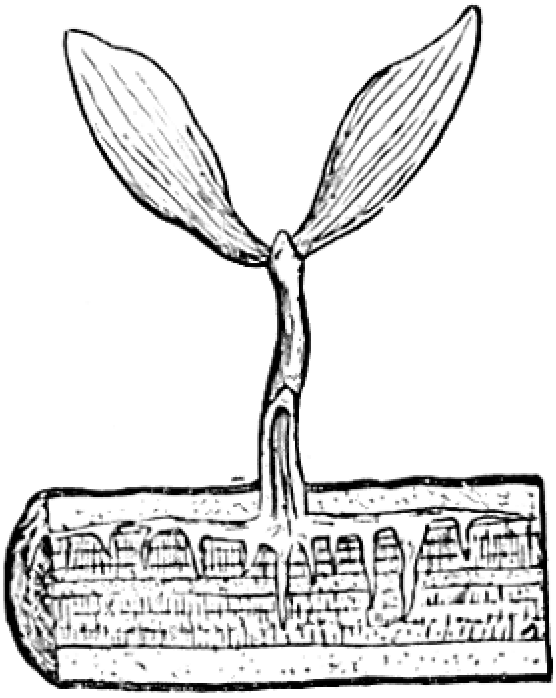
Fig. 29.—Young Mistletoe Plant.

The various roots mentioned should all be examined by the student, in addition to any others he may be able to secure.

THE STEM.

Take one of the most advanced of the bean plants and examine the stem. Note that the stem grows upward (or is erect); that it is not woody, but green or herbaceous; and that it is square, with a projecting ridge at each corner.

Observe that the leaves are attached in opposite pairs at points in the stem called *nodes*. The leafless spaces between these lobes are called internodes, and these become gradually shorter towards the top of the plant.

Cut through the stem transversely with a sharp knife, and observe the form of the section. Note the green layer of *epidermis* at the surface, beneath this the *cortex*, then a ring of white fibro-vascular bundles, inside which is a cavity surrounded by a layer of pith cells. Examine all these structures with a lens.

Peel a little of the epidermis from the surface of the stem, mount it in a drop of water and examine it under the microscope. Note that it consists of cells containing no chlorophyll; and possesses stomata, each enclosed by a pair of guard cells, as we observed in the fern.

We shall now examine the stems of various other plants in order to notice, as we did in the case of roots, variations in their forms and functions.

The surfaces of stems may be either smooth, hairy, or prickly; and the hairs or prickles, when present, have a protective influence, since they prevent the stems from being devoured by animals. Hairs also tend to prevent snails and slugs from ascending the stem to devour the leaves and flowers.

Young stems are usually green, but sometimes the epidermis cells contain a red cell-sap, especially when they are exposed to a strong light during their development. When the stem grows older it often becomes covered with layers of cork cells which are impermeable; but a loose cellular tissue takes the place of cork beneath many of the stomata, producing small swellings known as *lenticels*, and through these gases are still able to enter the stem.

As regards shape, the stem may be cylindrical, as in grasses and most trees; triangular, as in sedges; furrowed, as in the wild celery; or flattened, as in the sweet-pea.

Frequently the adult stem becomes hollow as in grasses and pinks; and usually it is the internodes which are hollow, while at the nodes the stem is solid. This arrangement gives a maximum of strength to a minimum of material, and hence it occurs most commonly in rapidly growing plants, in which a strong stem is formed in the most economical manner possible, and the material saved employed to produce a greater abundance of flowers and seeds.

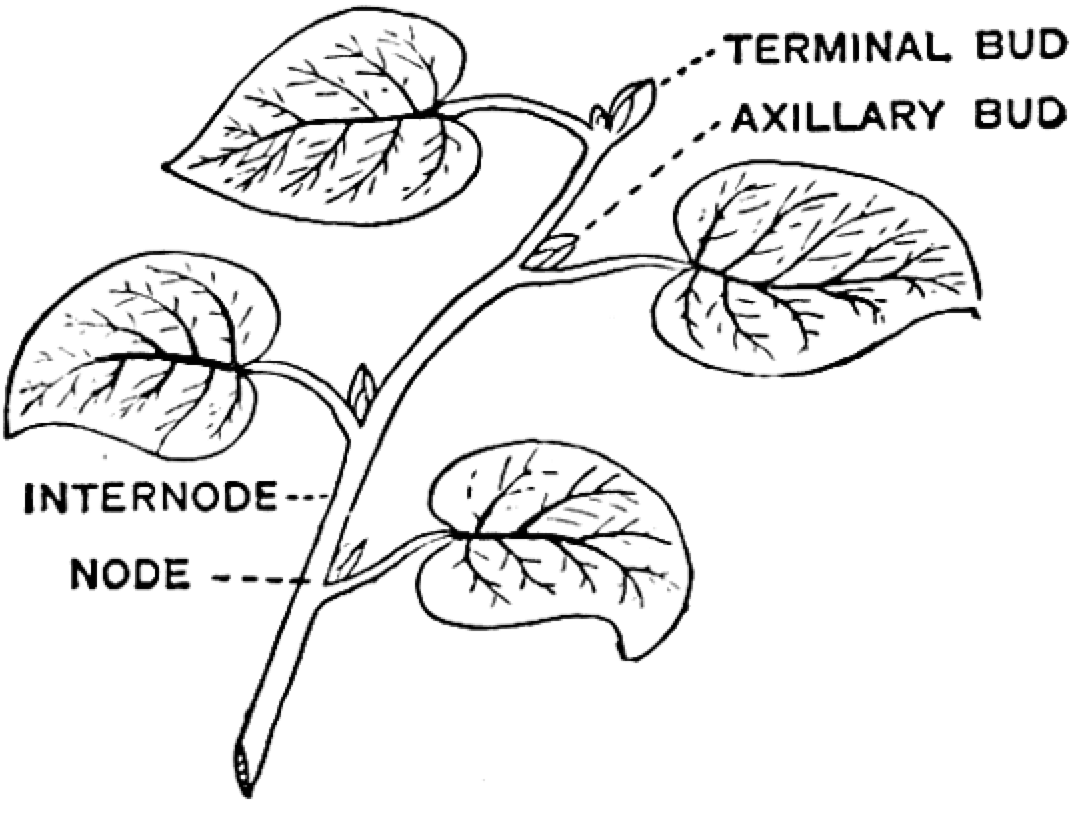

Fig. 30.—A Twig with Leaves and Buds.

Before a young stem branches we may generally see little prominences in the angle formed by the upper side of the leaf and the stem (Fig. 30). Each such prominence is a young bud which may give rise to a leafy or a flowery branch. The angle is called the *axil* of the leaf, and the bud formed in it is known as an axillary bud. Another bud may be seen at the summit of the stem; this is called the *terminal* bud.

Lateral branches arise only at the nodes, but all of the axillary buds do not develop into branches, for, if they did, the foliage would be too densely packed together, and sufficient light and air could not then reach all of the branches and leaves. It will be understood, however, that the mode of branching in the stem is determined by the position of the lateral buds and the extent to which these develop, but this subject will be taken up more fully when we are dealing especially with buds.

Stems differ very much as regards toughness and rigidity, as well as the age and size which they may attain. Herbaceous stems rarely last more than one season, even though they may grow to a considerable size and become tough and rigid. None of the British plants reach a very great height, with the exception of some forest trees; some of the herbaceous species, however, attain a height of twelve feet or more, while some climbing plants grow to a still greater height.

The principal functions of the stem are to give support to the leaves and flowers, and to arrange these parts in such a manner that they may most effectually perform their functions; also to form a channel of communication for the distribution of water and food materials between the various parts of the plant. But stems often undergo special modifications that enable them to perform certain extra functions varying according to the nature of the plant; and we shall now observe some of these modifications.

As a rule the stem of a plant is sufficiently strong and rigid to support the foliage, flowers and fruit that it bears, but some are so weak comparatively that they lie prostrate on the ground, as in some species of cinquefoil and certain vetches. Other weak stems seek the support of neighbouring objects, and the varied habits of these are so full of interest and instruction that the student should carefully study as many as possible.

Climbing stems, like the more rigid erect ones, grow upwards towards the light in order to secure the most favourable positions for flowering and fruiting, but would be prostrate, on account of their weakness, in the absence of some external support. Some attach themselves by means of aerial roots, as we have already noted in the case of the ivy; others twine themselves round suitable objects while a third class cling by means of special organs called tendrils.

Twining stems coil themselves round neighbouring objects, and generally ascend by the shortest possible path. Thus the stem of the hop will cling to an arched support until it takes a direction of about 45° from the perpendicular, and will then leave the arch and rise perpendicularly to seek further support above it. The convolvulus stem, on the contrary, will continue its windings along the horizontal summit of the arch.

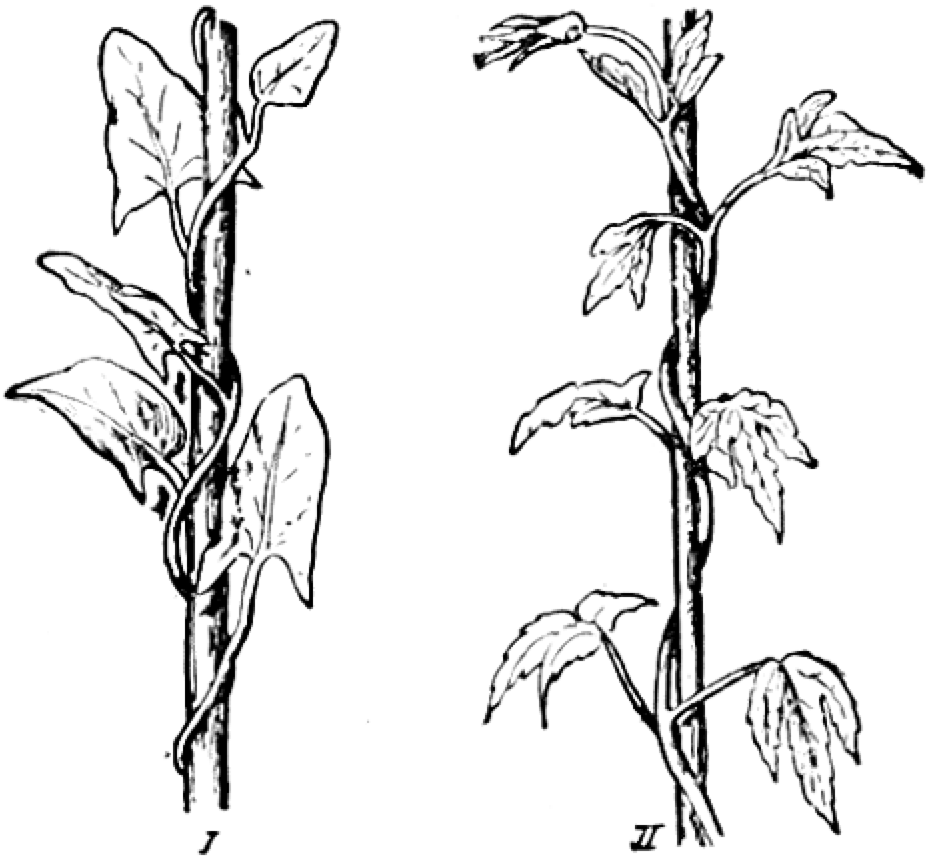

Fig. 31.—I., Convolvulus Stem twining against the Sun; II., Hop twining in same direction as the Sun.

Some twining stems follow a direction corresponding with that of the sun, as in the case of the hop and the honeysuckle; but the majority of them invariably take the opposite direction. In both cases the stems will resist any attempt to make them twine in a direction contrary to their usual habit. Further, each twining stem has the power of encircling objects up to a certain diameter; for instance, the hop is incapable of climbing a pole of a greater diameter than four inches.

A large number of plants support themselves by means of *tendrils*, which are *irritable* organs that coil round any thin supports they may happen to touch. Such tendrils are either modified stems or modified leaves, and their true nature may be determined by noting their position and mode of growth. If they arise in the axils of the leaves they are stem structures or specially modified branches, and often bear rudimentary scale-like leaves. Such are the tendrils of the passion-flower and the vegetable marrow. Leaf tendrils may represent a complete leaf, or they are modified portions of leaves. If the former they may be recognised by their position on the stem as well as by the presence of a bud in their axils. As an example of the latter note the tendrils of the pea (Fig. 50), which are modified leaflets of a compound leaf. The student should also examine the tendrils of a vine in full fruit, and note how the tendrils, opposite the leaves, are peculiarly adapted for the support of the heavy bunches of fruit.

In some climbing plants the leaf stalks or *petioles* are irritable, and serve the purpose of tendrils by twining round neighbouring supports. Examples of such may be seen in the clematis and the woody night-shade (Fig. 32).

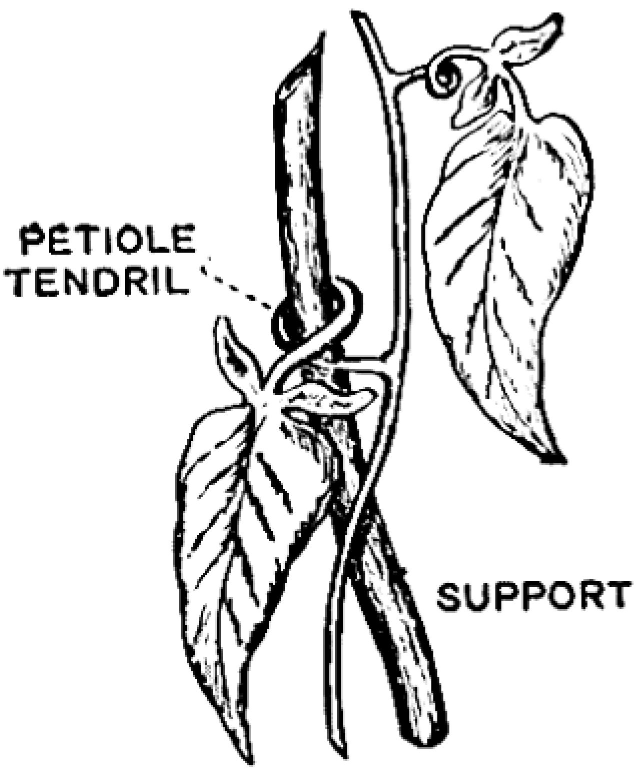

Fig. 32.—Leaf stalk of Woody Night-shade twining round a support.

If we examine tendrils that have entwined themselves round their supports we generally observe that the portions encircling the supports have become harder and more rigid, while the free portions between this and the plant have retained more of their original character, but have formed a few spirals in opposite directions. Thus the free portion becomes an elastic spring which enables the plant to yield more or less to the wind, and at the same time prevents any sudden shock that might injure the plant or tear it from its supports. Further, those tendrils which have failed to come into contact with suitable supports, and have consequently remained useless to the plant, generally coil up in one direction only, and soon wither and fall.

Another peculiar form of tendril is to be observed in the Virginian creeper (*Ampelopsis*), the clinging organs of which develop disc-like suckers at their extremities, thus enabling the plant to cling to any but smooth surfaces.

We will now examine the stems of the daisy and the primrose, which form the greatest possible contrast with the slender climbing stems. At first sight the plants appear to have no stem at all, the leaves apparently growing directly from the root. This, however, is not the case, for a true stem is represented by the thick mass of tissue at the bases of the leaves, though this is often spoken of as the "root-stock."

The strawberry plant has a similar "inconspicuous" stem, but in addition gives off slender lateral branches (*runners*) that grow to a considerable length along the surface of the ground (Fig. 33). The runner will be seen to arise from a bud situated in the axil of one of the leaves. At intervals of a few inches the runner produces a small scale-like leaf, in the axil of which a bud is formed. Roots develop from the base of the bud, which then gives rise to

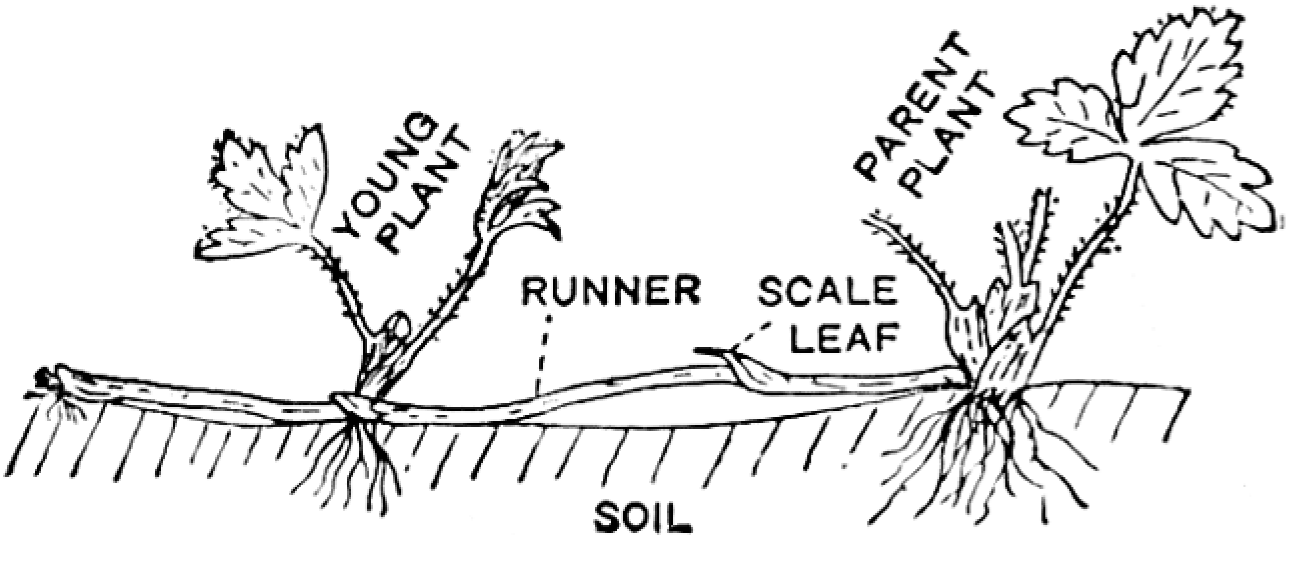

Fig. 33.—Runner of Strawberry.

a new plant; and, when the latter has reached a self-supporting stage, the runner between it and the original plant withers away.

Somewhat similar runners are produced as lateral shoots from the house-leek, but these are much shorter, and are generally known as *offsets*. Each one carries a large bud from which root fibres are developed (Fig. 34).

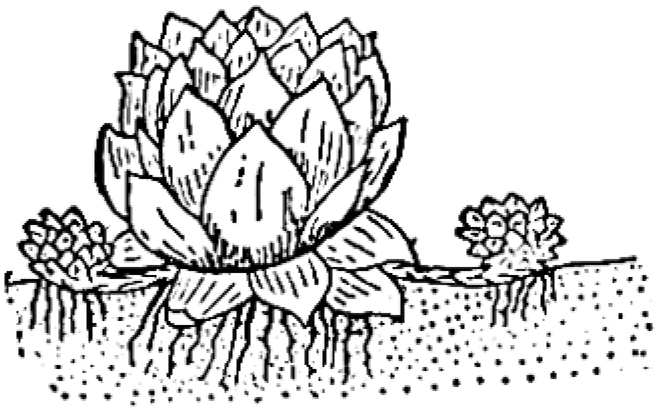

Fig. 34.—Offset of the House-Leek.

If we pull up a plant of mint we find that lateral branches from the lower part of the stem run horizontally under the surface of the ground (Fig. 35). These branches are whitish in colour like roots, as they contain no chlorophyll, but they are not roots since they give rise to scale-like leaves, in the axils of which buds are formed. The buds develop into leaf-bearing ascending axes (*suckers*) which rise out of the soil, and soon acquire the characters of aerial stems.

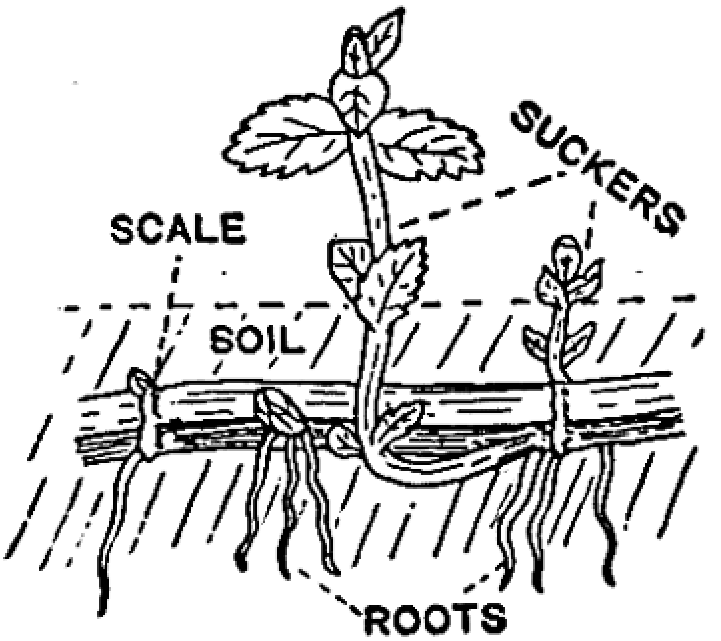

Fig. 35.—Underground Stem and Suckers of Mint.

Now dig up an iris plant or a Solomon's seal, and note that it, too, has an underground stem that grows horizontally near the surface (Fig. 36). It is root-like in appearance, but its true stem-like nature is revealed by the presence of the white terminal bud and the shoots that rise and develop into new plants. The true roots are the fibres that descend from the under surface. It is also much thicker than the corresponding stem of the mint, and it persists after the ascending shoots have decayed. Thus, while the newest shoot alone exists, near the terminal bud, the scars of the previous shoots are visible on the upper surface of the older parts. Stems of this kind are known as *rhizomes*. Similar stems, though of a slender type, are to be found in the wood-sorrel and the ground ivy.

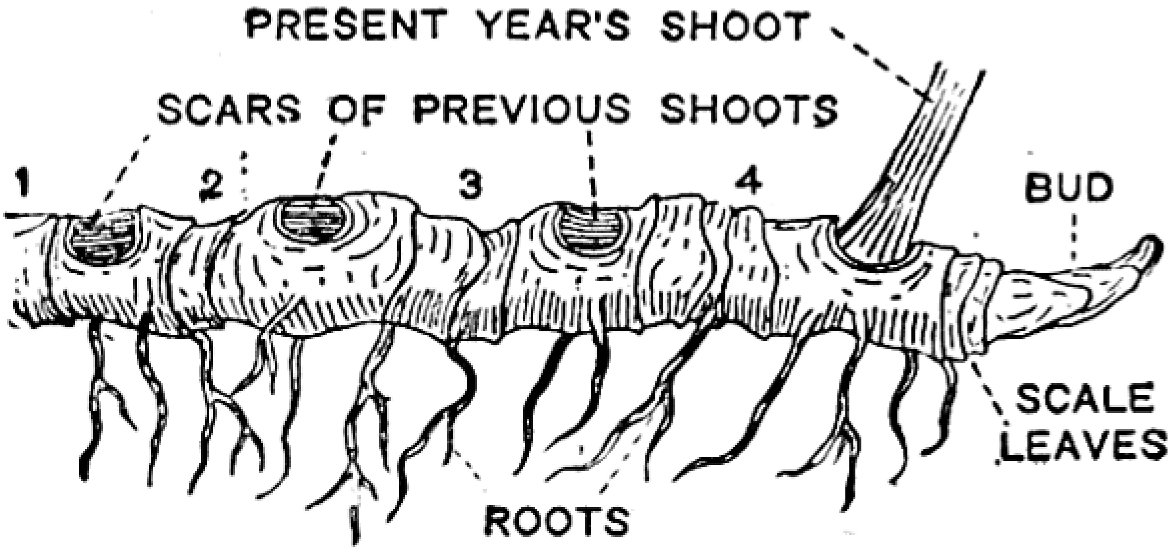

Fig. 36.—Rhizome of Solomon's Seal.
The numbers represent the growth of successive years.

For the further study of underground stems we obtain a potato plant. In this plant we find three distinct kinds of stems. First there is the green erect aerial stem that bears the leaves, flowers and fruit. Then there are root-like underground stems, easily distinguished from roots by the presence of scale-like leaves; and, thirdly, there are the *tubers* or swollen underground stems which we use as food. The tuber is easily recognised as a stem not only by its mode of growth, but also by the presence of "eyes," which are modified buds. The creeping stem is the means by which a large store of food is conveyed to the tuber, chiefly in the form of starch; hence, after the former has decayed, together with the plant from which it grew, the tuber is capable of producing new plants by the development of its buds. The potato-grower obtains his plants

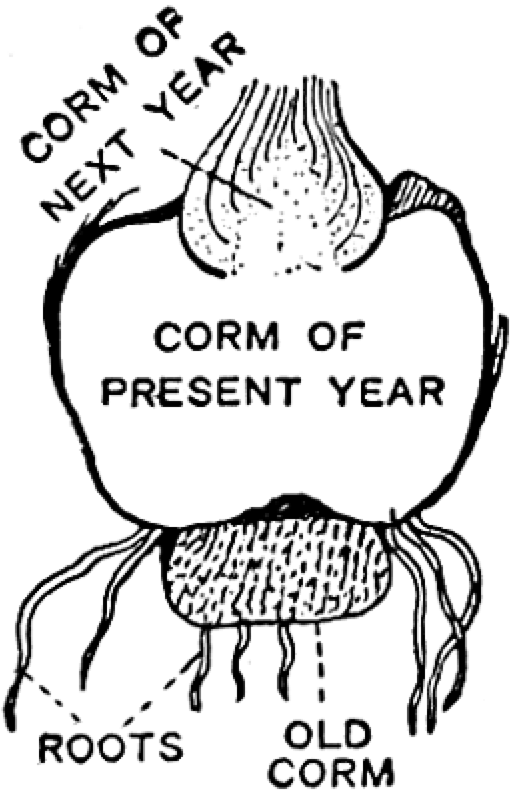

Fig. 37.—Corm of Crocus.
Longitudinal Section.

by sowing his "seed potatoes," which are cut up for the purpose into pieces, each of which has at least one eye.

Next examine the crocus plant (Fig. 37), or the gladiolus. It consists of leaves (and flowers if in bloom) that arise from a bulb-like body, below which are the root fibres. We cut the bulb-like body longitudinally through the middle, and note that it is not a true bulb, though popularly so called. A true bulb, such as we find in the onion and the lily, is really a bud, consisting mainly of a mass of fleshy leaves packed closely one over another; but the structure before us is a thick fleshy mass that exhibits no such division into scales. It is, in fact, a swollen stem known as the *corm*. It is formed at the base of the plant after the flowering season is over, and contains a store of food material for the development of a new plant in the following season, all loosely ensheathed in a few leafy scales; consequently the best time to examine a corm is some time after the plant has flowered. We then observe one or more buds attached to it, on the top in the case of the

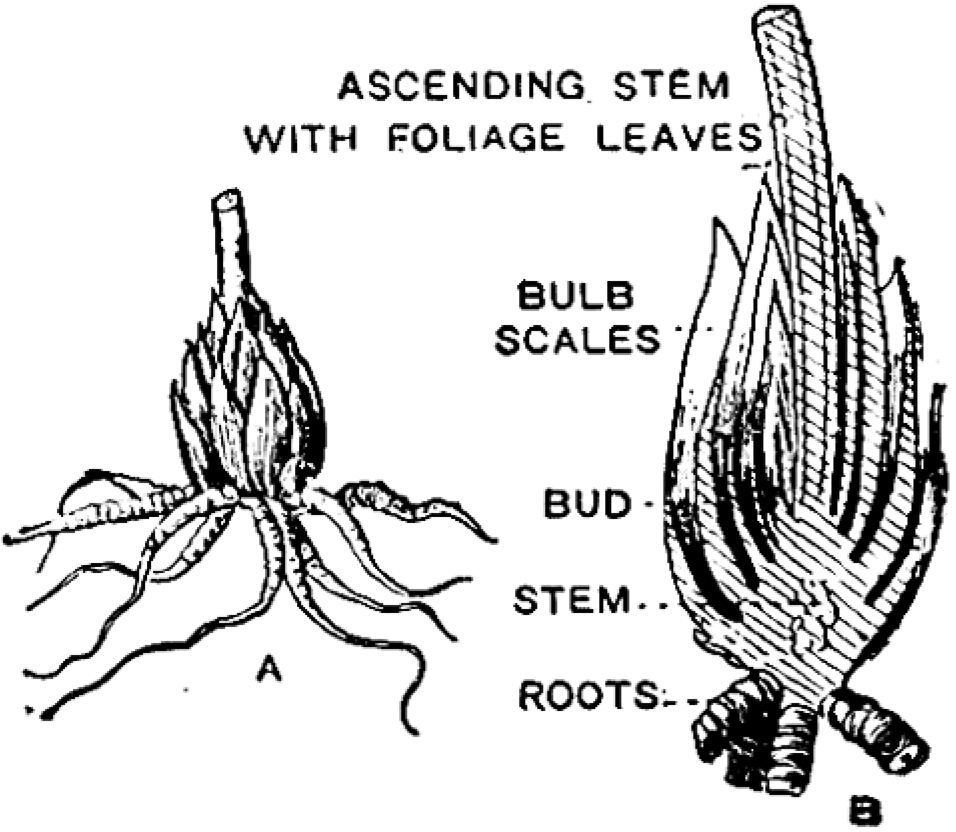

Fig. 38.—Scaly Bulb of Turk's Cap Lily (Lilium Martagon).
A, Entire; B, Median Longitudinal Section.

crocus and the gladiolus, but at the side in some other corms This bud develops into a new plant in the following year, using up the store of food reserved in the corm, which consequently shrivels up; and each plant forms a new corm after it has flowered, to which the remains of the old one still adhere.

In order to thoroughly understand the difference between a corm and a *bulb* we make a similar longitudinal section of an onion or the bulb of a lily (Fig. 38) or hyacinth. We note that nearly the whole mass of this consists of fleshy leaves, and is therefore a bud rather than a stem. All the leaves, however, arise from a hard mass of tissue at the base, from which the root fibres also grow downward. This is the true stem of the plant.

SPINES AND PRICKLES.

The student should now obtain a variety of stems bearing *spines* and *prickles*, for the special observation of these appendages. They should be studied very carefully, not only as to their general form and probable function, but also as to their origin and mode of growth.

Some of these, as the thorns of the hawthorn and sloe, are evidently branches that have ceased to grow, and have been converted into hard and sharp organs that protect the trees from the ravages of herbivorous mammals. We know that they are branches because we see immediately beneath their bases the scar of a fallen leaf, thus showing that they have each developed from a bud originally situated in the axil of the leaf, just after the manner of lateral branches generally. Further, they frequently themselves bear buds and small leaves, as shown in our illustration (Fig. 39). Such spines contain fibro-vascular bundles, continuous with those of the stem on

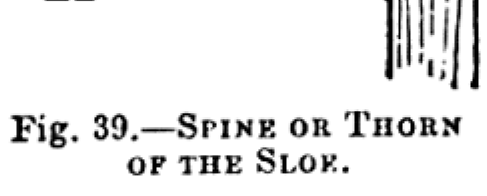

Fig. 39.—SPINE OR THORN OF THE SLOE.

which they grow, just like ordinary branches; and, consequently, are not easily torn off. Also, if torn off, they leave a deep wound in the stem due to the severing of the bundles.

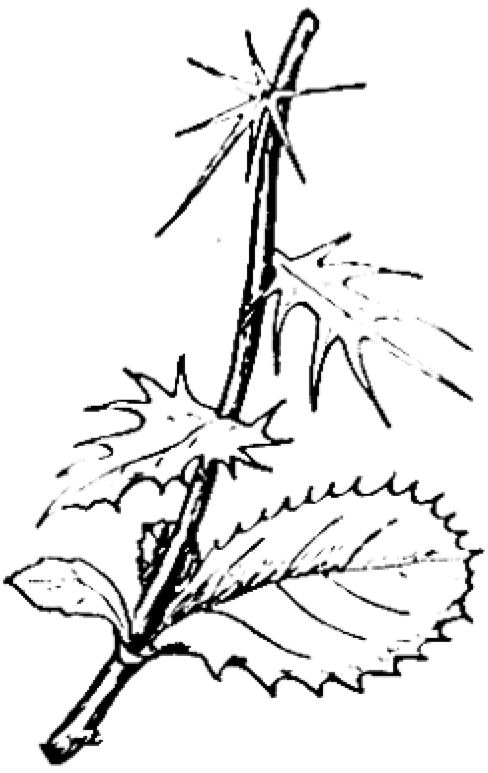

Fig. 40.—Branch of Barberry, showing transition of foliage leaves into Spines.

Some spines, however, are either modified leaves or portions of leaves, and our illustration of the barberry shows the gradual transition of leaves with spines at their margins into branched clusters of hard spines. On the gorse we find spines some of which are leaf structures, while others are stem structures. The former are narrow-pointed leaves, for some of them may be seen to have buds in their axils; but the latter are the hardened and sharply-pointed extremities of the branches.

Prickles, such as those of the rose, (Fig. 41) are of a very different character from the thorns and spines we have been considering. If we tear them off they do not leave deep wounds in the stem, but only a scar on the surface; hence we know that they do not contain vascular bundles continuous with those of the stem. And if we note their distribution on the stem we find that it is impossible to designate them either as modified leaves or branches, for they do not fall in with the order of leaf arrangement, nor have they buds in their axils; neither do they grow from the axils of the leaves. They are merely outgrowths of the superficial tissues of the stem, irregularly arranged, and produced as "emergencies" for the benefit of the plant.

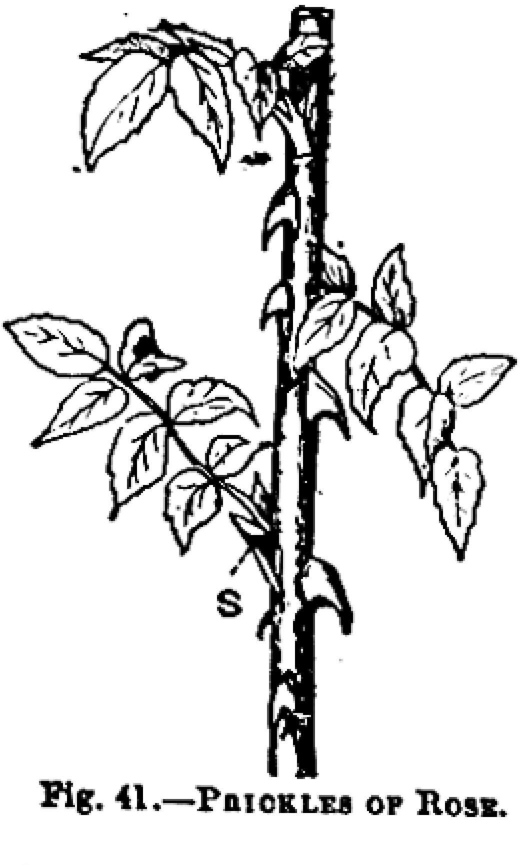

Fig. 41.—Prickles of Rose.

Prickles, of course, serve to protect the plant from the attacks of herbivorous animals, but they often do more, especially when they curve downwards as they do in the rose and the bramble, for in this case they are so many hooks that help to support the stem, and therefore assist the plant in climbing among the surrounding bushes and herbage.

An acquaintance with plants in their habitats teaches us that the formation and development of hairs, spines and prickles depends to a great extent on external conditions. Thus, the same plant that produces these parts when growing in a poor dry soil fully exposed to the rays of the sun, becomes of a much softer and less aggressive character when grown in a rich, moist soil. Under the former circumstances the plant not only protects itself from herbivorous animals, but also, by converting some of its buds and leaves into spines, reduces the amount of its foliage, and thus economises its scanty supply of water.

STRUCTURE OF STEMS.

Having now studied the principal of the various kinds of stems, we shall procure a few with the object of noting their general structure as far as it can be made out without the aid of a microscope. We have already done this in the case of the bean stem, and other stems, such as those of the sunflower, elder, elm, iris, lily, etc., may now be procured for our present purpose.

Cut through the stem of the sunflower, either transversely or obliquely, with a very sharp knife or razor, and note its structures in order, commencing with the outside—(1) The *epidermis*, which looks green, though it is colourless and transparent. The green colour is due to the thin layer of (2) *cortical tissue* beneath the epidermis, consisting of layers of cells with chlorophyll. (3) A ring of *fibro-vascular bundles*, enclosing the soft cellular (4) *pith* that occupies the middle of the stem. Examining the section with a lens we note that the ring of bundles, which consists of bast fibres outside and woody fibres within, is broken up, more distinctly in the younger parts of the stem, by rays of the pith which extend outwards between the bundles. Note the hairs on the epidermis.

Cut through the stem again just below a node, and then gradually slice it away towards this node, and note the vascular bundles from the ring passing outwards into the leaf-stalk.

Make a similar section of one of the thick young shoots of the elder tree. Note the same structures as seen in the sunflower stem, and in the same order. Observe especially the large proportion of pith. Split open the stem, remove the pith and examine it. Also allow the pith to dry, and then note its extreme lightness—it is much lighter than cork. Examine the surface of the stem for lenticels (p. 50). If the surface is brown, the colour is due to the formation of cork cells.

Now take a branch of the elm tree, and examine one of the very young twigs of the present season's growth. Note that it is green at the tip, but brown lower through the formation of cork. Observe the very distinct lenticels on the brown portion. A section of the twig reveals the same structures as we have noticed in other stems.

Next, cut a thin slice out of the thickest part of the branch with a saw, and rub down one of the cut surfaces on fine glass-paper until it is very smooth. Examine it with the aid of a lens, and note the following in order, commencing at the surface—

1. The bark, composed of brown cork cells.
2. A light cortex beneath the bark.
3. A ring of bast fibres (*phloëm*), sometimes called the inner bark.
4. The lighter "sap wood," composed of concentric rings varying in number with the age of the branch.
5. The darker " heart wood," also composed of rings, at the centre of the stem. (The above are numbered 1 to 5 respectively in Fig. 42, p. 62.)
6. A small amount of pith in the very centre.
7. Pith rays extending from the centre through the whole thickness of the wood, dividing it up into a number of wedge-shaped portions

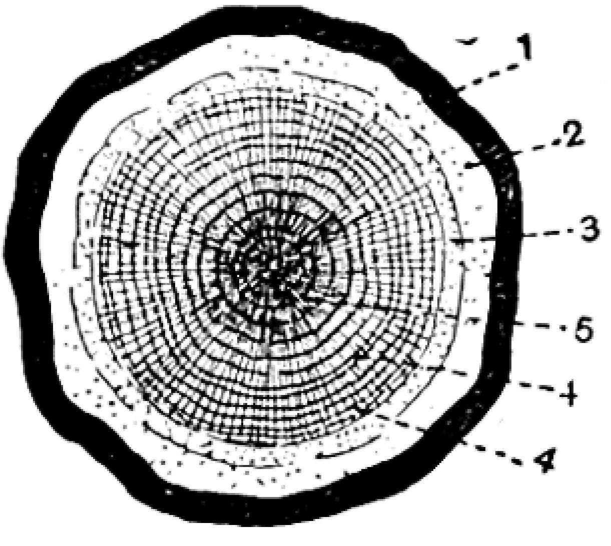

Fig. 42.—SECTION OF STEM WITH 15 ANNUAL RINGS OF WOOD.

The stems we have examined up to the present are all of the same type. They are termed *exogenous* or outward-growing stems, because the new wood is formed outside the older wood. The thick branch of the elm differs from the others in having its wood arranged in several rings, but the latter were annual stems (stems living for one season only) or stems of one season's growth, while the former has a separate ring of wood for each year of its existence. In such stems a new ring is formed each year, outside the older wood, and underneath the bast; hence the bast and bark are pushed outwards as the stem increases in thickness, while the number of rings of wood represents the number of years during which it has been growing.

A few simple experiments will enable us to learn something of the function of the stem as a means of communication between different parts of the plant:—

1. Remove a complete ring of bark from a small branch still attached to a tree, and note that the leaves do not wither. Hence the bark is not concerned in the transmission of moisture from the roots to the leaves.

2. Cut away a ring of both bark and sap-wood from another branch. The leaves wither, therefore the fibres or vessels of the sap-wood form the channels through which water, absorbed from the soil by the roots, reaches the leaves.

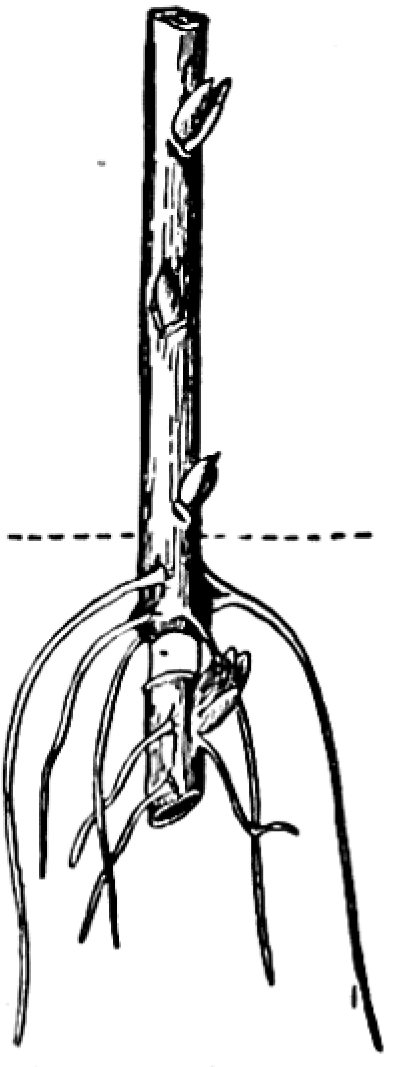

Fig. 43.—A RINGED BRANCH OF A WILLOW (*Salix*) SPROUTING IN WATER.

3. Remove two small branches from the willow or other

tree. Cut away a ring of *outer bark only* near the bottom of one, and a ring of both outer and inner bark (bast) near the bottom of the other. Put both in water and observe them from day to day. In the former root fibres and buds will be seen to sprout with equal rapidity both above and below the cut ring. The outer bark, consisting of nothing but dead cork cells, has nothing to do with the transmission of water either upward or downward. In the latter buds and roots will also develop both above and below the ring, but more rapidly *above* than below. Those originating below the cut ring are fed only from below, by water rising in the uninjured sap-wood; but those above the ring are fed by additional food prepared in the leaves, which passes downwards through the bast vessels.

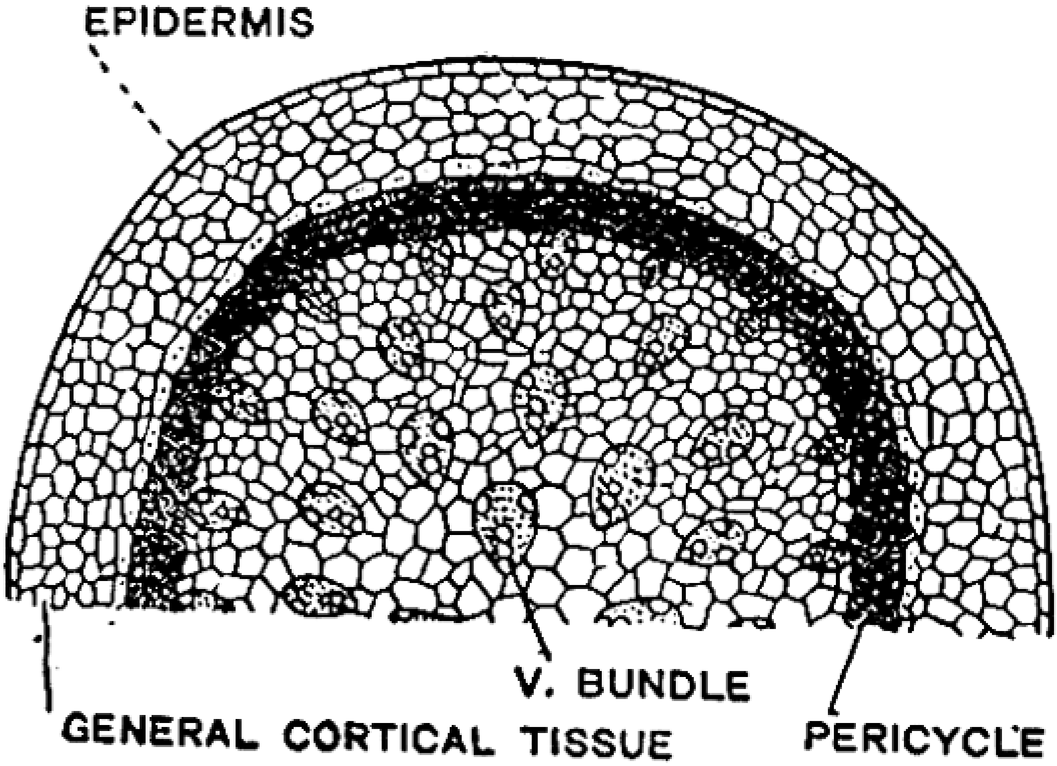

Fig. 44.—Half of a Transverse Section of a Monocotyledonous Stem.

Now examine the stem of the maize, or the floral stem of the lily or iris. It is surrounded by a thin colourless layer of epidermal cells, beneath which are chlorophyll-bearing cortex cells, and has no true bark of dead cork cells as we observed in the elm and elder.

Cut a transverse section of the stem and examine it with a lens. Note, in order, commencing at the surface—

1. The epidermis and cortex as mentioned above.
2. A ring of denser cellular tissue (*pericycle*) inside the cortex.
3. A mass of cellular tissue filling the whole interior, and containing in all parts small bundles of fibres.
4. The absence of a central pith.

Here, then, we have a very different type of stem. It does not increase in thickness by the addition of wood externally. In fact there is no increase in thickness after the stem is once formed, so that the older portions are of practically the same thickness as the younger. Such a stem is termed a *monocotyledonous stem.* The origin of the name is given on p. 109.

THE LEAF—STRUCTURE AND FUNCTION.

We now return to the bean plant for the special study of its leaves. First note that the leaves are arranged in opposite pairs, and that the distance between the nodes of the stem decreases in length towards the summit. At the base of each leaf there is a pair of leaf-like expansions. Such expansions at the base of a leaf-stalk, whether merely small scales or large and leaf-like, are called *stipules.* In the axil of each leaf there is a bud, and some of these buds have already developed into branches in which the character of the main stem is repeated.

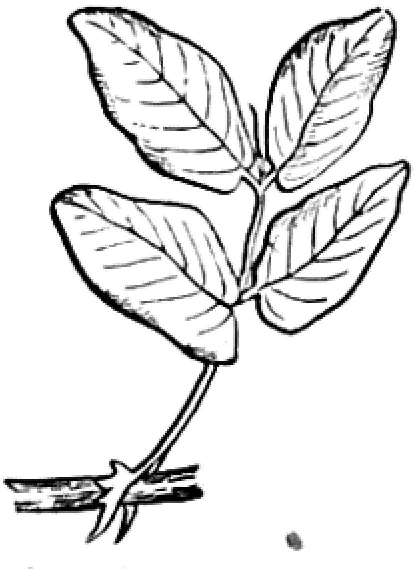

Fig. 45.—LEAF OF THE BEAN, WITH STIPULES AND RUDIMENTARY TENDRIL.

Note that each leaf consists of a stalk (*petiole*) that bears four or six oval *leaflets*, and terminates in an imperfectly formed tendril. Observe the midrib running centrally through each leaflet from base to tip, the principal *veins* branching from the midrib, and the delicate network of smaller veins distributed in all parts of the leaf. (All the veins contain bundles of vessels derived from those of the stem, and the spaces between them are filled with soft cellular tissue.) Make a drawing of the complete leaf with its stipules, and represent, as accurately as possible, the arrangement of the veins.

Strip off a small piece of epidermis from the lower surface of the leaf. There may be some difficulty in doing this, but if the leaf is first torn across, the colourless epidermis may possibly be seen projecting beyond the torn edges. By pulling at this with a fine pair of forceps a little fragment may be peeled off for examination. Mount it in a drop of water, and view it under the microscope. Note the epidermal cells, without chlorophyll, joined at their edges; and the crescent-shaped guard-cells, with chlorophyll, surrounding and regulating the size of the stoma between them. Make a drawing of the epidermis, and compare with that of the frond of the fern.

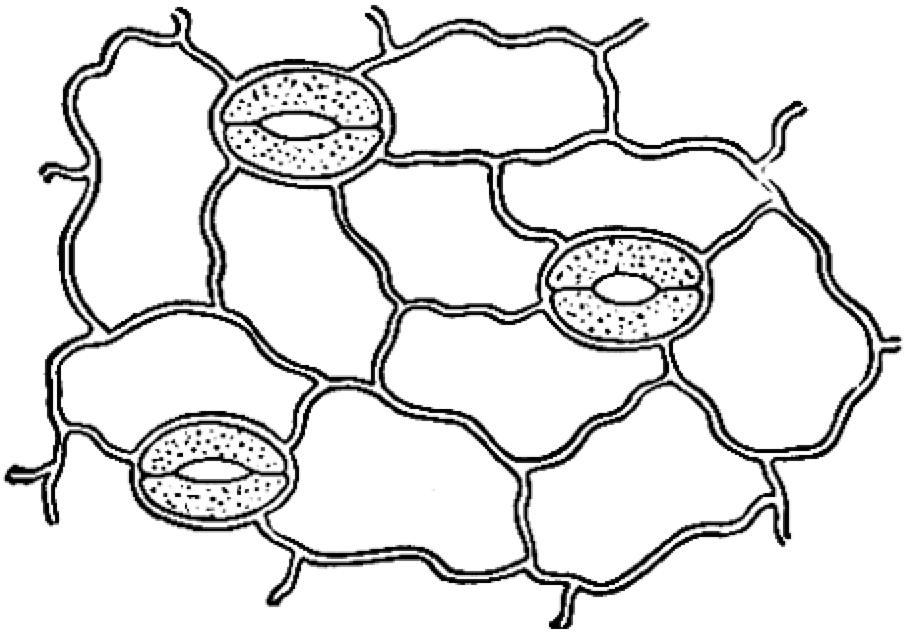

Fig. 46.—THE EPIDERMIS OF THE LEAF OF THE BEAN, MAGNIFIED.

Examine a fragment of the epidermis of the upper surface, and note the absence of guard-cells and stomata.

Remove a small bean or other plant from the soil, and place it without injury in a vessel of the form shown in

The stopper should be of india-rubber, perforated, and divided down the middle, so that it will grasp the stem firmly and be perfectly air-tight. The vertical tube attached to the side of the vessel, if not graduated by engraved lines, may have a scale drawn on a narrow strip of paper and fixed to it. The divisions should represent definite volumes, such as cubic centimetres. Fill the vessel with water, replace the stopper firmly, and set aside for observation. The volume of water becomes less, and the amount of loss may be seen by observing the scale. Enter in a book the amount of loss in equal intervals of time, and note that it is less during darkness than in the light, and also that it varies with atmospheric conditions.

Fig. 47.

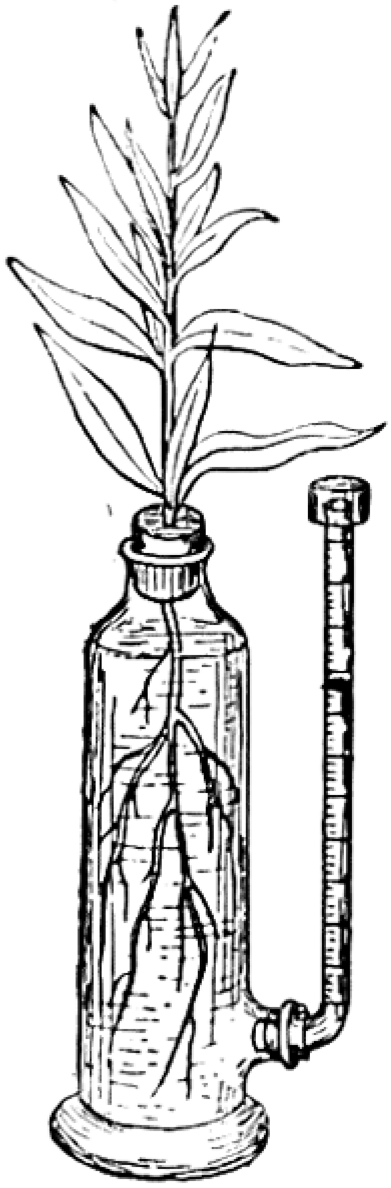

Fig. 47.—APPARATUS FOR ESTIMATING THE ABSORPTION OF WATER BY THE ROOTS, AND THE LOSS BY EVAPORATION FROM THE LEAVES.

Now take a bean plant, or any other plant with moderately large and broad leaves, growing in a pot or tub, and shut it up in a perfectly dark place for a whole day. Cut a circular piece of opaque brown paper or card, having about half the area of the leaf or less, put it on the top of a leaf, and fix it by means of a stitch made with needle and cotton (Fig. 48). Put the plant out in the full sun for a whole day, then remove the leaf with brown paper attached, give it a momentary immersion in boiling water to kill it, and then put it in methylated spirit, after having removed the piece of paper. The spirit will dissolve out all the chlorophyll, reducing the leaf to a very pale colour. When this is the case, immerse the leaf in a weak solution of iodine, and note that the whole leaf with the exception of the circular patch previously hidden by the paper turns to a dark purplish colour, thus proving the presence of starch, while there is no evidence of the presence of this compound in the circular patch itself. If the leaf is now replaced in the spirit, a uniform pale colour is again restored, but the presence of starch in all but the central patch may be demonstrated any number of times by transferring it from the spirit to the iodine solution.

This experiment should be tried with the leaves of several different plants, some of which give much more striking results than others. Those of the primrose, tropæolum, and cabbage are well suited for the purpose.

The foregoing observations and experiments throw much light on the functions of leaves, which may be thus briefly summarised:—

1. Leaves are the respiratory organs of the plant, since they allow a free exchange of gases with the atmosphere by means of their stomata.

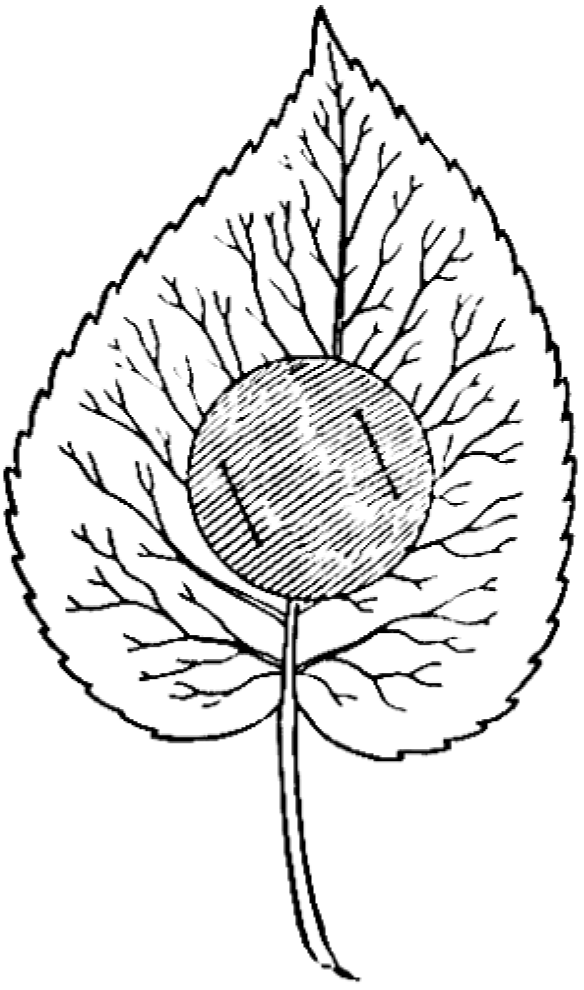

Fig. 48.—LEAF WITH BROWN PAPER ATTACHED, TO PROVE THAT STARCH IS FORMED ONLY UNDER THE INFLUENCE OF LIGHT.

2. The chlorophyll of the leaf, which, as we have proved, is itself formed only under the influence of light, has the power, under this same influence, of decomposing the carbonic acid gas of the atmosphere, and of building up with the carbon so obtained, together with the dissolved mineral substances absorbed by the roots from the soil, the sugar, starch, and other organic compounds of the plant. Some of the material thus formed in the leaves is transmitted to the stem and root in a soluble state, and often stored in these organs in enormous quantities.

3. Water absorbed by the roots passes up the stem to the leaves, where a large proportion of it is lost by evaporation through the stomata. Water lost by evaporation in this way is being continually replenished by the roots,

and thus there is a steady upward current by means of which new mineral matter is constantly supplied. The stomata are reduced in size by the collapse of the guard-cells when "transpiration" is too active, and when the water supply in the soil is deficient. They also close in darkness, when less food is needed; and by so doing they also prevent the plant from becoming too cold, for evaporation is always accompanied by a reduction in temperature.

FORMS OF LEAVES.

Before quitting the study of leaves we must observe a number of their general characters—their variety of form. arrangement of veins, and the different ways in which they adapt themselves to the nature of their surroundings. In order to do this we shall have to examine a considerable number, and to this end the student should take a country ramble, supplied with a book for notes and sketches, and a lens to assist his observations. We must necessarily be very brief in dealing with this part of our subject, and our instructions must be accepted as merely suggestive, and by no means exhaustive.

Note the long blade-like leaves of grasses, observing that they spring from the swollen nodes of the jointed stem, for which they form a close sheath before becoming free. Observe also the leaves of the wallflower, which, after uniting with the stem, are continued some distance downward in the form of a ridge or angle on the latter.

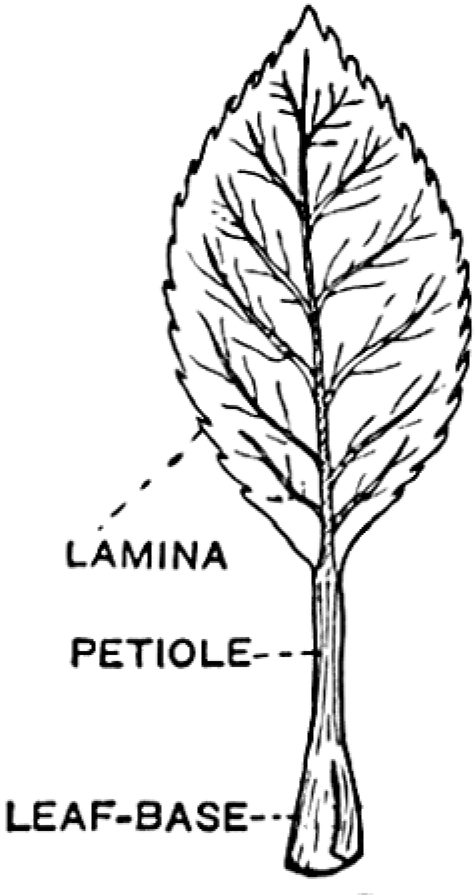

Fig. 49.—A TYPICAL SIMPLE LEAF.

Some leaves are *simple*; that is, their flat part or *lamina* is not divided into distinct portions, though they may be very deeply divided. Such is the case with the leaves of the oak, hazel, ivy, dandelion, etc. These simple leaves exhibit a great variety of form, and the student should make a series of drawings illustrating the more typical as well as some very exceptional shapes.

In compound leaves, of which we have already seen an example in the bean, the lamina is divided into distinct parts called leaflets, which may be arranged in opposite pairs along the central stalk as in the rose and the pea, or may all radiate from one point of the stalk as in the horse-chestnut.

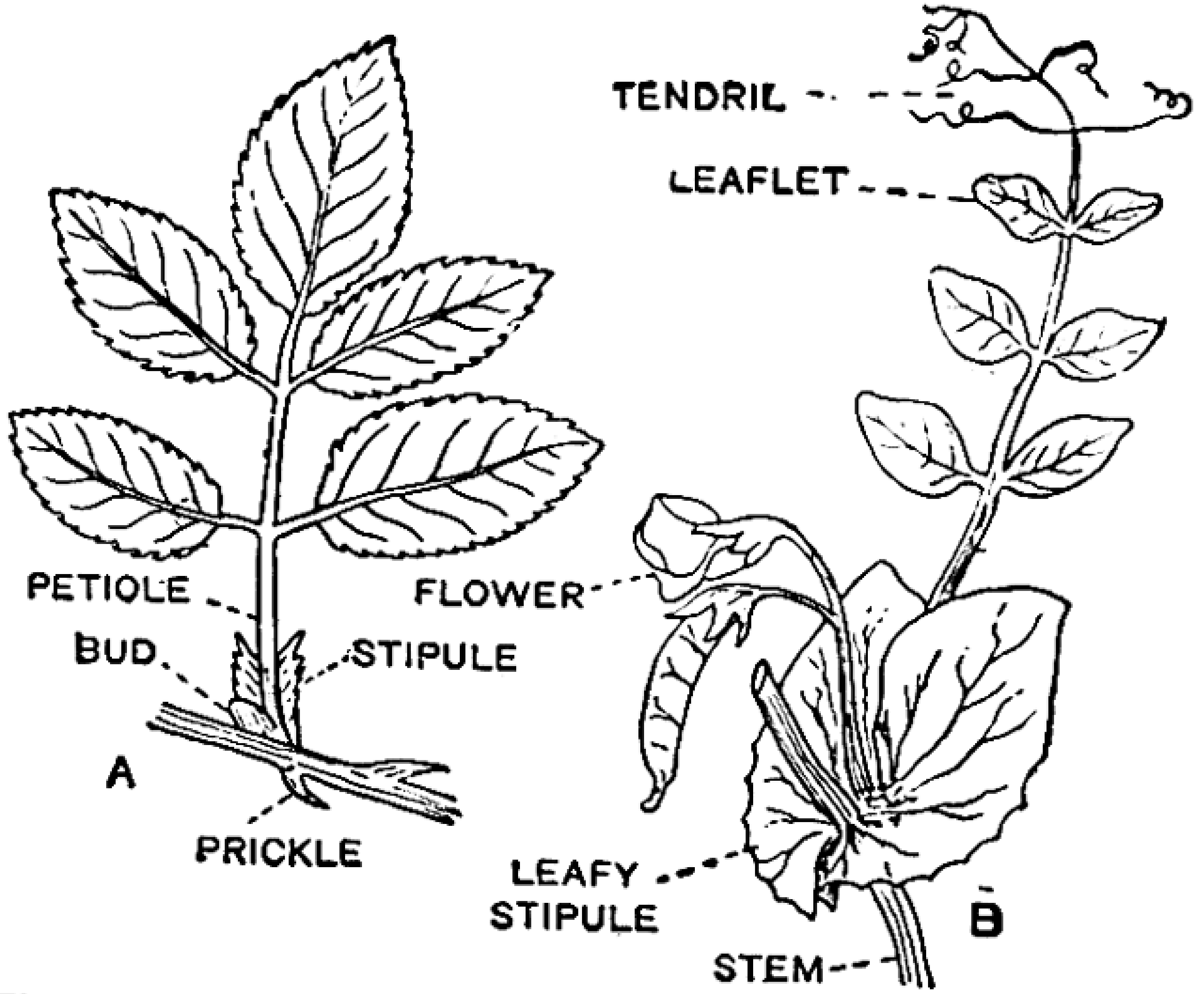

Fig. 50.—A, Compound Leaf of Rose, with five Leaflets and Stipules; B, Compound Leaf of Pea, with terminal Leaflets modified into Tendrils.

The study of the arrangement of the veins of the leaf is also instructive. Note that the leaves of all grasses, orchids, flags, wild hyacinths and daffodils have all their principal veins running parallel through the entire length, and that these leaves are more or less elongated and blade-like. The leaves of most of our trees and herbs, however, have their principal veins branching off from the midrib on either side, while the smaller ones form a delicate network such as we observed in the bean-leaf. Further, it will be remembered that we examined two distinct types of stems—one with a bark, wood in a ring or rings, and a central pith; the other with neither bark nor pith, and with small bundles of vessels distributed throughout the softer tissue forming the bulk of the stem. Now it is important to note that the plants bearing leaves with netted veins also possess stems of the former type, while those with parallel veins have stems of the latter structure.

Compare the simple leaves of the ivy and the beech, both of which are of the net-veined type. Note that in the former the principal veins all radiate from one point at the base, while in the latter they branch off from the midrib almost throughout its length. Now, since a compound leaf is produced by the division of the lamina between the principal veins, it is easy to see that the former, so divided, would produce a compound leaf with radiating leaflets. Such an arrangement of veins is termed *palmate venation*, and the leaves, both simple and compound, more or less divided in this fashion, are called *palmate leaves.* The arrangement of veins in the second instance is called *pinnate venation*, and by the incision of the lamina a *pinnate leaf* is produced, which, in the case of the compound leaf, would have opposite leaflets.

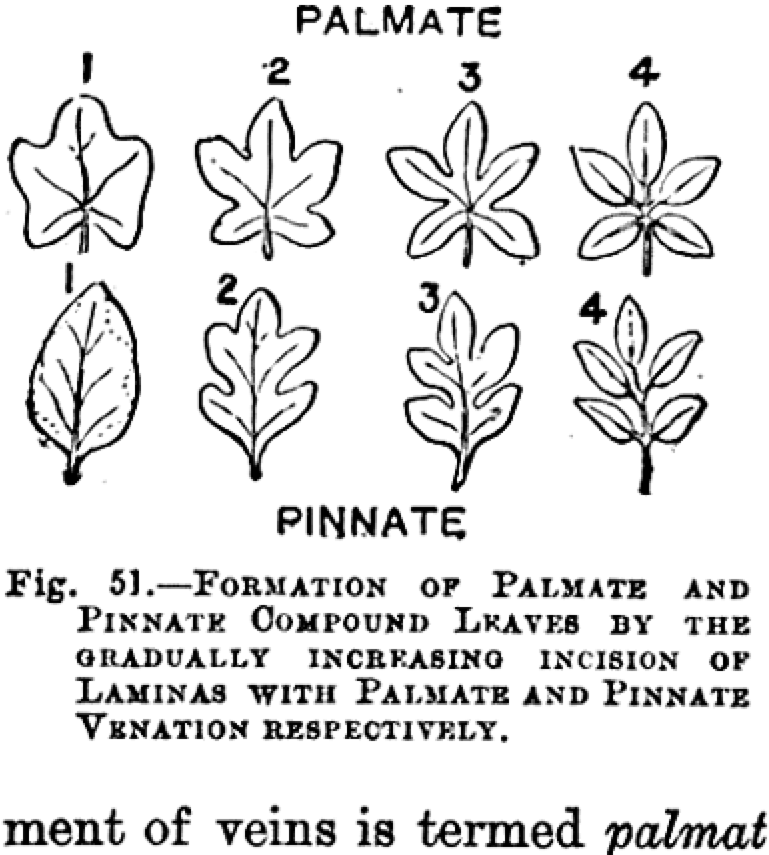

Fig. 51.—Formation of Palmate and Pinnate Compound Leaves by the gradually increasing incision of Laminas with Palmate and Pinnate Venation respectively.

The arrangement of the veins, and especially of the more delicate ones that are often difficult to trace, may be beautifully shown by soaking leaves in water until the soft cellular tissue of the lamina has decomposed, and is so loosened that it can be removed with a soft brush. In this way the most perfect specimens of skeleton leaves may be obtained, nothing remaining of them except the bundles of vessels which disintegrate much more slowly than the cellular substance.

Note that while some leaves have a distinct stalk (*petiole*), in others (wallflower and shepherd's purse) the lamina extends down to the stem of the plant. The latter are called *sessile leaves*.

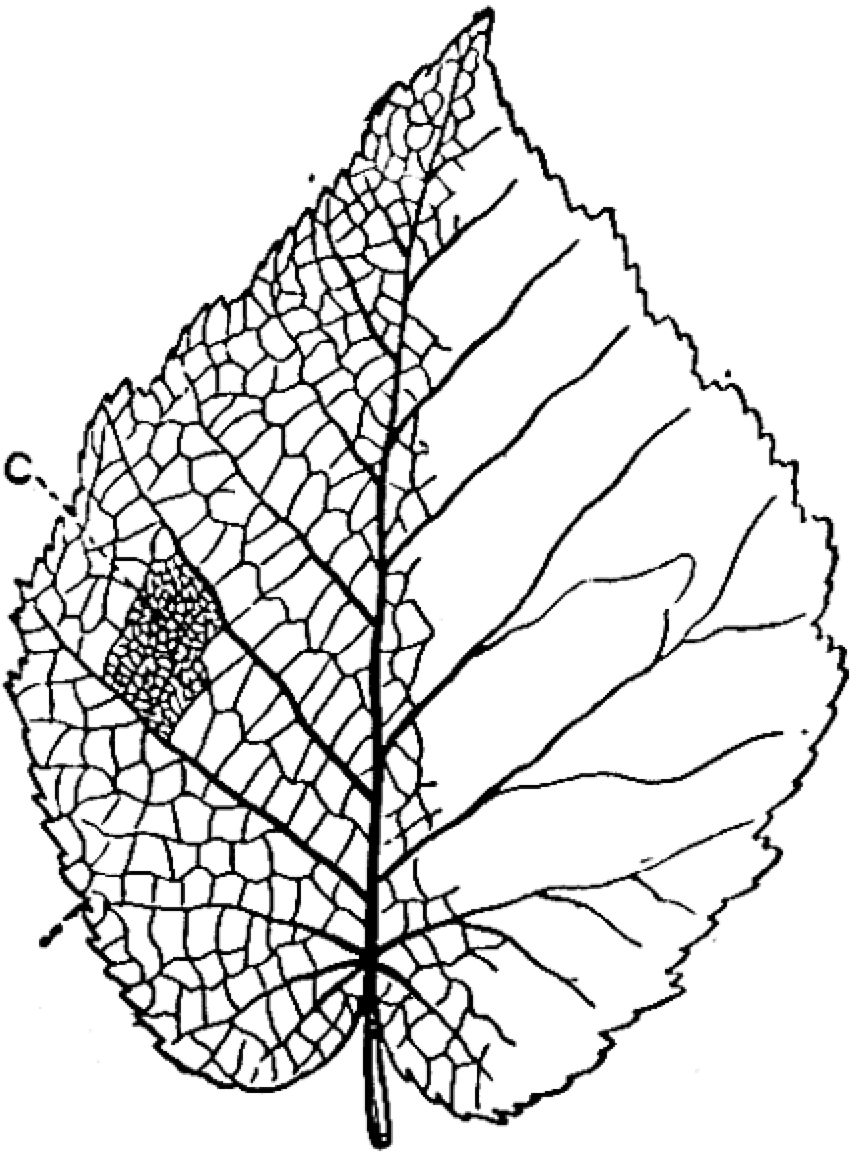

Fig. 52.—Arrangement of Veins in the Leaf of the Pear.
The Principal Veins only are shown on the right side, and the smallest Veinlets at C.

Next observe the different kinds of margins possessed by leaves. Some are plain or *entire* (privet and wallflower); while others have teeth which either stand out at right angles to the general direction of the edge (holly), or, as is more commonly the case, point in one direction, more towards the apex of the leaf, and thus resemble the teeth of a saw (rose, dead-nettle, stinging-nettle, etc.). Note also the hairy margin of the beech leaf, the wavy or sinuate margin of the oak, the irregularly toothed edge of the dandelion, the spiny margin of the holly, and various other modifications of leaf margins, all of which should be drawn from nature.

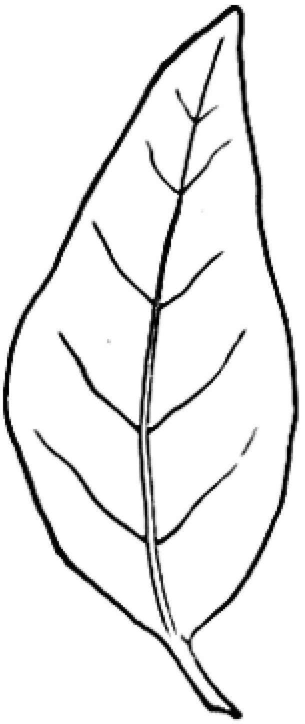

Fig. 53.—Leaf of the Privet.

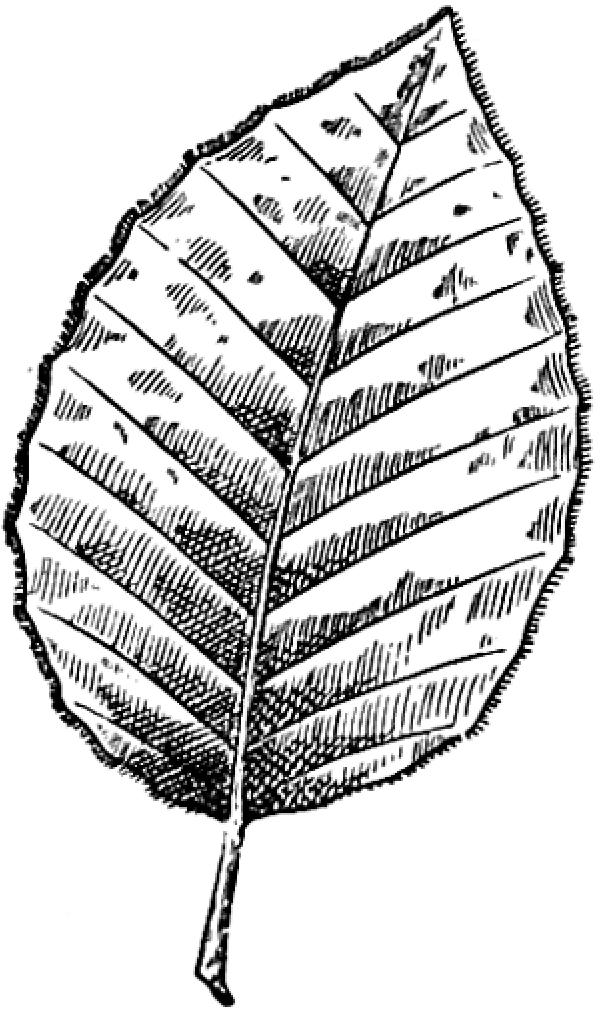

Fig. 54.—Leaf of the Beech.

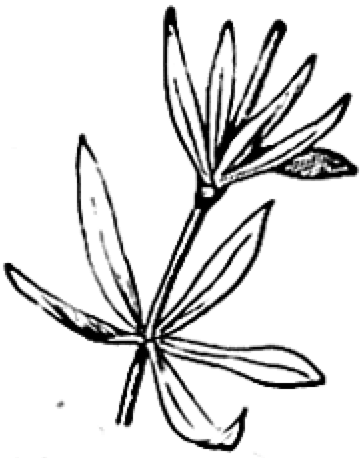

Fig. 55.—Whorled Leaves.

Observations should also be made of the different ways in which leaves are arranged on the stem. Note the leaves of the bed-straw and the goose-grass, arranged in whorls around the nodes of the stem; and the pairs of opposite leaves in the stitch-wort, chickweed and sycamore; and note that in cases where the leaves are placed either in pairs or in whorls of more than two, each leaf arises vertically over the gap formed by leaves of the pair or whorl below it.

In other cases the leaves are either arranged alternately on opposite sides of the stem, or in such a manner as to form a spiral. The nature of the spiral may be easily determined by tying a piece of cotton to the base of a leaf, and carrying it in order to the bases of the leaves above, twisting it around each one. Suppose, for instance, we do this in the case of a young shoot of the hazel; we find that each leaf is one-third round the stem as compared with the one below it, and consequently the fourth leaf is vertically above the first, being the starting leaf of a second turn of the spiral (Fig. 56).

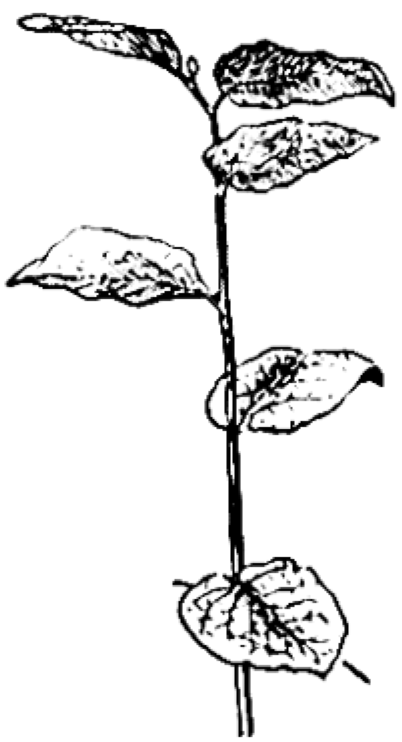

Fig. 56.—YOUNG SHOOT OF THE HAZEL, WITH LEAVES SHOWING A DIVERGENCE OF ONE-THIRD.

It is most instructive to observe the various modifications of leaves by which the plants are adapted to the conditions under which they live. Thus, plants that grow in dry situations often develop a thick cuticle which prevents too great a loss of moisture, and many of them also produce spine-like leaves and branches to the same end. Some leaves are covered with such a dense coating of hairs that they can never be wetted by rain or dew, the globules of which roll off as from a greasy surface, and thus the stomata are always open for the necessary exchange of gases. Some of the hairs of the leaf of the stinging-nettle are connected with glands that produce an acid irritating fluid for the protection of the plant. The submerged leaves of aquatic plants are generally much divided, in order that a much larger surface may be exposed to the water for the absorption of carbonic acid gas dissolved in it, as in the common water-crowfoot. Some aquatic plants have floating leaves (water-crowfoot and water-lilies) which are provided with stomata on the *upper surface,* which is in contact with the atmosphere, and these also have large air-spaces within to render them light. Many of the sea-side plants that grow in the scanty soil of barren cliffs store up their moisture in thick fleshy leaves, while varieties and allied species of these same plants growing in moister situations have leaves with thin blades. The leaves of evergreens have a thick cuticle to enable them to retain their moisture during the winter when the root fibres do not absorb water so readily, while on the approach of this season the leaves of other plants and trees either wither on the plant or fall. Some compound leaves are so sensitive to light and atmospheric conditions that they assume sleeping attitudes at times; thus the triple leaves of the clover fold upwards at night and thus give off less heat by radiation towards the sky. These and many other adaptations of leaves should be observed by the student, and notes should be made and explanations sought.

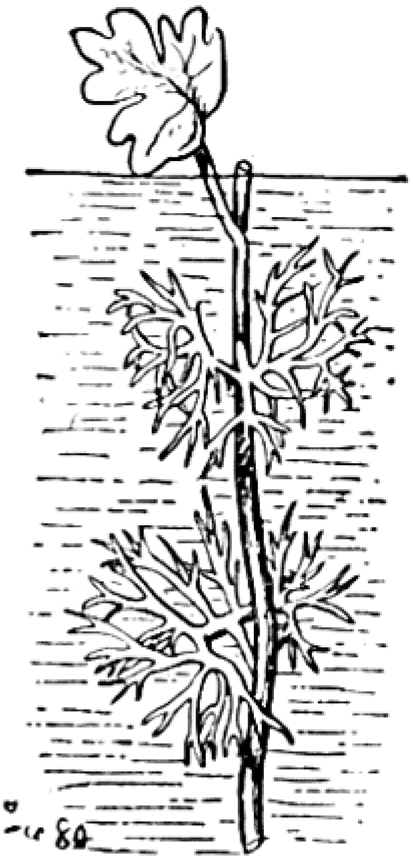

Fig. 57.—Floating and Submerged Leaves of the Water Crowfoot.

Lastly, we must consider briefly the cause of the fall of the leaf in deciduous plants and trees in the autumn. At the end of the summer season, when the activity of the leaves is over and they have been deprived of the greater part of the food substances they contain, a layer of cork cells is formed across the base of the leaf, and this shuts off all further supplies of mineral food from the soil, at the same time weakening the junction of leaf and stem so that the former is shed. It is a vital action of the living plant tending to its own preservation, as may be proved by the fact that if a branch is killed by boiling water or other means the leaves do not fall, but wither on the stem.

The Flower—General Structure.

Examine the flower of the bean plant, and note all the following parts in the order named:—

1. It is supported on a stalk—the *peduncle*.

2. A green outer cup (*calyx*) with five points. It is composed of five united leaves (*sepals*) each with a midrib terminating at one of the points mentioned.

3. A conspicuous whorl of leaves (petals), five in number, inside the calyx, forming together the *corolla*. The upper petal is large, expanded at its free end, and folded over the others. Two others at the sides are attached by distinct narrow stalks. The lower part of the corolla is composed of two united petals (forming a kind of keel) which readily tear apart.

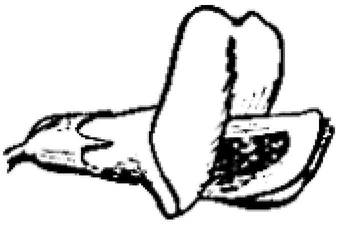

Fig. 58.—The Bean Flower.

4. Pull off the petals, and note within the corolla ten *stamens*, each consisting of a stalk-like *filament* terminating in a small knob—the *anther*. Observe that nine of the filaments are united for the greater part of their length, while the tenth is quite free. Note that the free portions of the stamens all bend sharply upward (Fig. 59).

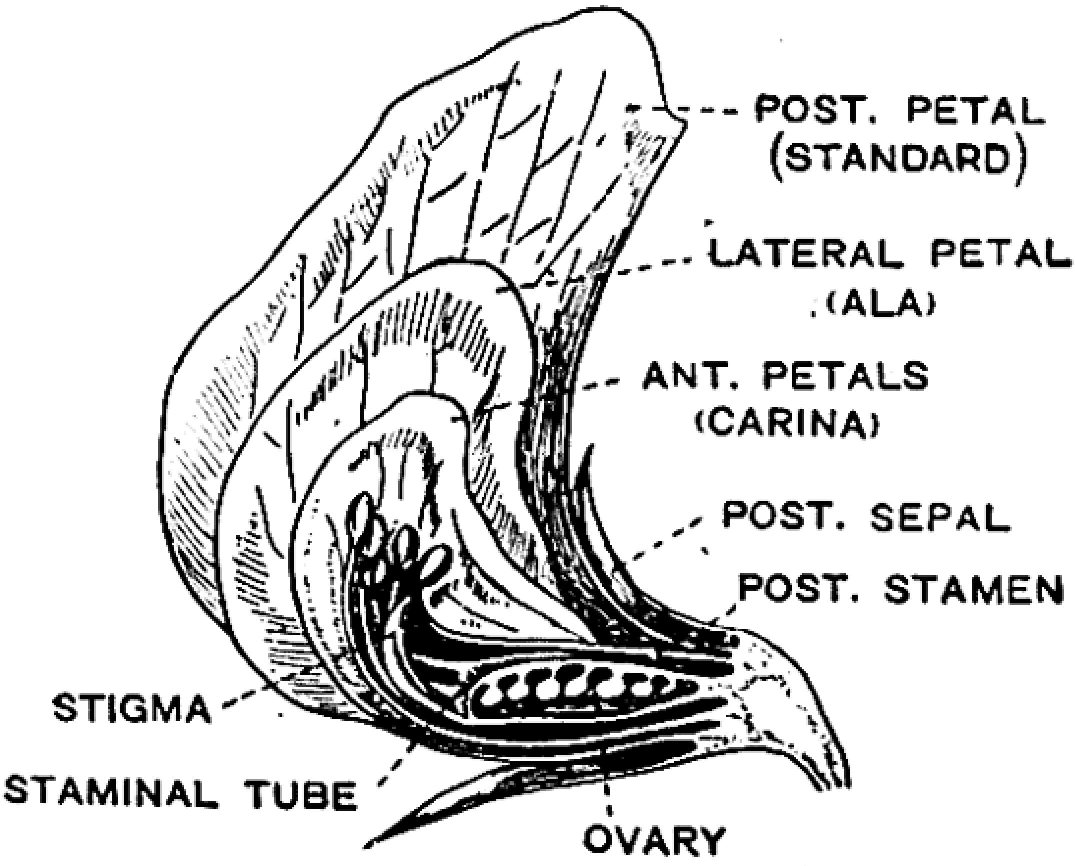

Fig. 59.—Section of the Pea Flower.
(The structure of the Bean Flower is practically the same.)

5. Press the anthers gently on a clean glass slip, and if a dust-like deposit is formed on the glass examine it with a lens or the low power of a microscope, noting that it

consists of little oval cells (*pollen grains*) having projections of the cell-wall round the middle part. If no such deposit of pollen is obtained, break open one of the anthers on a glass slip with needle-points, and examine. The anther has four *pollen sacs*, each of which contains many pollen grains.

6. Tear open the stamen tube, and note within it a long green body (the *ovary*), tapering towards the tip, flattened at the sides, and terminating in a point (the *style*) which bears a tuft of stiff hairs.

7. Slit open the ovary carefully, and note that it encloses a cavity in which are several little oval bodies (*ovules*) attached by very short stalks.

Thus we have learnt that the bean flower consists of four whorls of modified leaves, the outer one being the calyx, composed of sepals; the second the corolla, formed of petals; the third the stamens; and the fourth, called the *pistil*, consisting of ovary and style.

Now that we have briefly studied the structure of one particular flower it is necessary to examine many others in order to become acquainted with their varied forms and adaptations, and to this end the student should proceed to examine various garden and wild flowers, especially the latter, provided, of course, with sketch-book and lens. The following instructions will serve as a general guide for the earlier part of this work.

Note that some flowers (primrose, daffodil, mustard, buttercup, poppy, campion, stitchwort, etc.) have their parts symmetrically arranged round a common centre, and are therefore called *regular* flowers; while others, like the bean, violet, snapdragon and foxglove, are *irregular*.

Some flowers have no peduncle, and these, like leaves without petioles, are said to be *sessile*. In other cases we may find one or more of the four whorls absent; thus, the little flowers of the goose-foot, knot-grass, dock, sorrel, nettle, besides the flowers of several of our forest trees, have either no calyx or no corolla; and the daffodil, lilies and hyacinth have only one whorl of leaves (the *perianth*), representing both calyx and corolla of a more highly organised flower. Either stamens or pistil may also be absent, though this is the case principally with the small green and inconspicuous flowers of certain herbs and trees, in which either calyx or corolla, or both, are also wanting.

In the bean flower we observed that the stamens, or, rather, all but one, were united; but in most flowers they are free. Stamens are also very variable in number, there being many in the buttercup, dog-rose, and allied flowers, and only one or two in the flowers of privet, willow, birch and poplar. They are often inserted in the base of the flower, below the ovary, as in the bean, buttercup, wallflower, violet, geranium, etc.; but sometimes above the ovary, as in the fool's parsley; or in the calyx round the sides of the ovary, as in the dog-rose and fuschia. Frequently, too, they are inserted in the corolla, as in the primrose (Fig. 79) and dead-nettle.

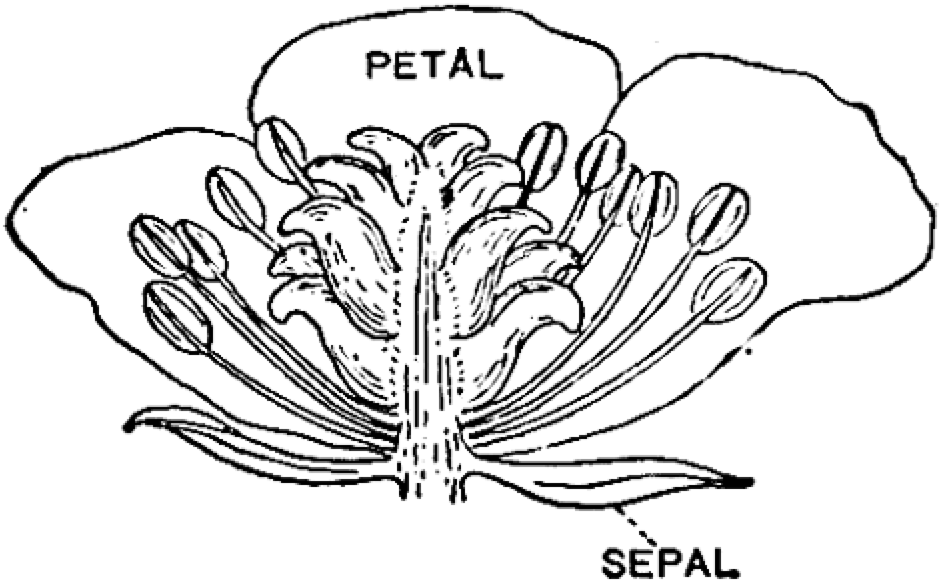

Fig. 60.—Section of the Buttercup, Enlarged.

It is most important that the student should note carefully the relative positions and *insertions* of the various parts of flowers, for the affinities and classification of flowering plants are based largely on these characters.

A great variety of form and structure is also to be seen in the pistils of flowers. In its most perfect form the pistil consists of three distinct parts—the *ovary*, containing the ovules, a slender stalk-like part called the *style*, and some kind of expansion on the summit of the style called the *stigma*. Often, however, the style is absent, so that the stigma is *sessile* on the ovary. The pistil is made up of one or more modified leaves called *carpels*, and the number of these is indicated by seams that are visible more or less distinctly on the outer surface. Thus, the pistil of the bean and the primrose consists of only one carpel, while that of the violet has three. Sometimes the carpels are welded together, as in the violet and the lily, but are often separate or distinct, as in the buttercup and the blackberry. Transverse sections should be made of the ovaries of all flowers examined, in order to see the number of compartments or distinct cells enclosed, and to note how the ovules are attached.

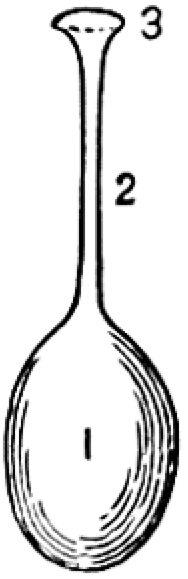

Fig. 61. A TYPICAL PISTIL. 1, Ovary; 2, Style; 3, Stigma.

The ovary is said to be *superior*, or free, when it is above the calyx, as in the bean, primrose (Fig. 79), violet, etc.; but *inferior* when it is below the calyx, as in the willow-herb and evening primrose. In the latter case the ovary is either inserted in the fleshy summit of the flower stalk, which is called the *receptacle* of the flower, or the tube of the calyx surrounds, and is adherent to, the wall of the ovary. Of course, if the ovary is superior, the calyx must necessarily be inferior, and *vice versâ*.

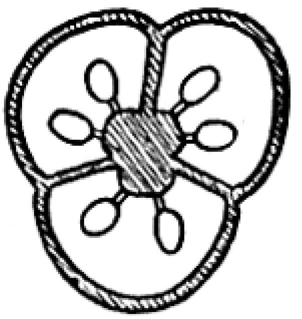

Fig. 62.—TRANSVERSE SECTION OF THE OVARY OF THE LILY.

INFLORESCENCE.

The student should observe also the different ways in which flowers are arranged on the floral stalks, and here again we shall call attention to only a few typical cases to serve merely as a preliminary guide in assisting the student's own observations.

Some flowers are stalked along a common axis, as is the case with the wallflower and antirrhinum. Such an arrangement is called a *raceme*. If the branches of a raceme are themselves branched, so that each bears more than one flower, a *compound raceme* is produced. Sometimes the lower branches of a raceme are longer than the upper ones, thus bringing all the flowers to one level, as in the candytuft.

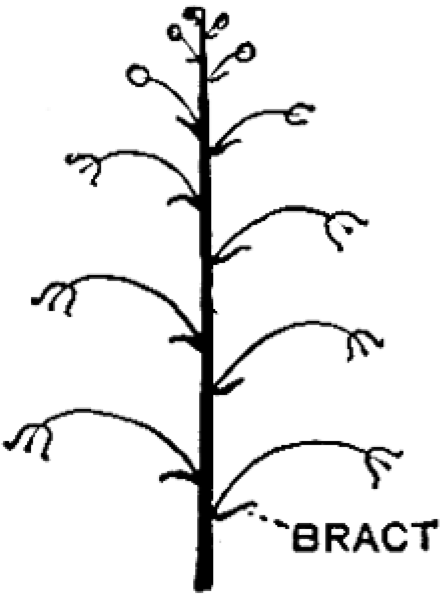

Fig. 63.—A Simple Raceme.

The flowers of the plantain and the wheat are arranged in a raceme, without stalks, and this particular variety is called a *spike*. Many of our trees produce dense spikes of imperfect flowers in which either pistil or stamens are absent, and which are more or less pendulous; such are called *catkins* (Fig. 65).

When the flower stalks all branch from one point on the main stem, the arrangement is called an *umbel* (Fig. 66).

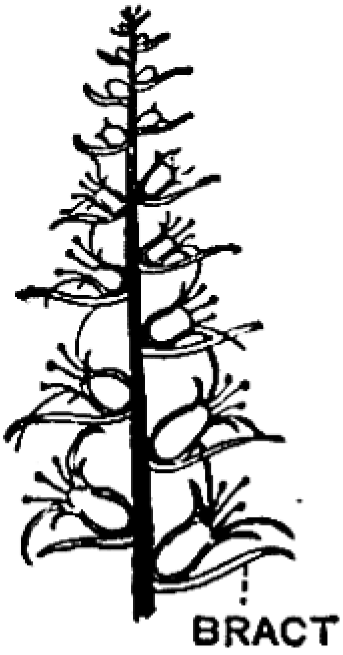

Fig. 64.—The Spike (Diagrammatic).

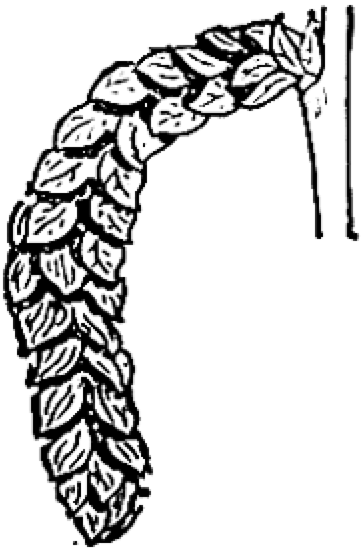

Fig. 65.—A Catkin.

Examples are to be seen in the cherry and the ivy. An umbel also may be compound, as in the fool's parsley and carrot.

If we examine the daisy we find that it is not a single flower, but a dense cluster of very small flowers, the outer of which are white and the inner yellow, all attached to a broad receptacle, and forming what is called a flower-head or *capitulum*.

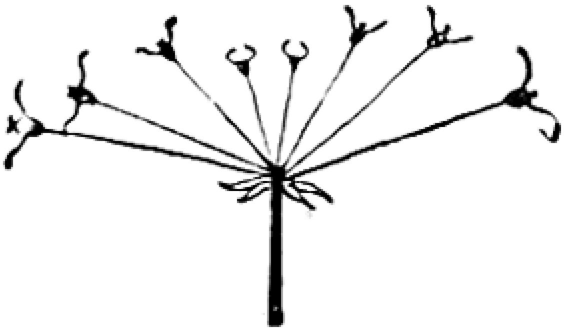

Fig. 66.—A SIMPLE UMBEL.

In pinks and campions the main floral axis terminates in a flower, and the lateral branches continue to grow and bear flowers after the growth of the main axis has ceased. The arrangement thus produced is called a *cyme*.

Other forms of *inflorescence* or flower arrangement should be studied and sketched from nature, and in all cases the student should observe the order in which the flowers of each cluster open.

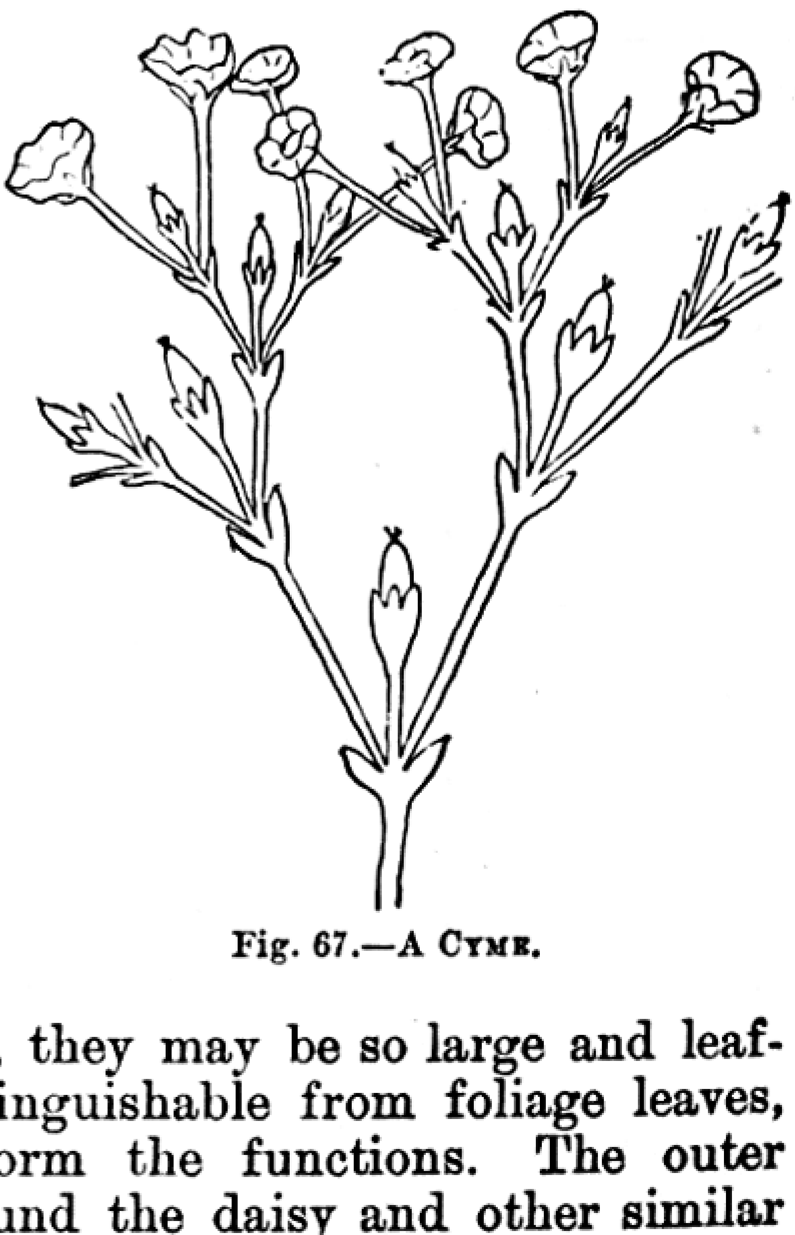

Fig. 67.—A CYME.

At the base of a flower stalk, or, if the stalk is absent, at the base of the flower itself, we often meet with a leaf or scale known as the bract. These bracts are of a protective nature, since they serve to shelter the flower buds. In some cases they even protect the perfect and fully expanded flower, as in the cuckoo-pint. Though sometimes they are very inconspicuous scales, they may be so large and leaf-like as to be hardly distinguishable from foliage leaves, of which they also perform the functions. The outer whorl of green leaves round the daisy and other similar "composite" flowers must not be regarded as a calyx, since the calyx is the outer whorl of a single individual flower. It is rather a whorl of bracts.

The Sexual Organs of Plants.

Returning again to our selected type—the bean, let us watch the progress of a certain flower from the time that it first opens. Some time after the corolla has expanded we find that the anthers have opened and exposed the pollen grains, which remain so lightly attached that they are easily removed when touched. At this time we speak of the anthers as mature. A corresponding state of maturity is also assumed by the stigma, and is denoted by the presence of a small amount of gummy substance that is secreted by its cells. Pollen grains may soon be seen attached to the stigma, and the flower is frequently visited by bees which we know have previously visited flowers, since a yellow dust of pollen grains may be seen on their bodies.

We watch the bees at their work, and find that they pass rapidly from flower to flower of the same species. As each bee arrives at a flower it rests on the two lateral petals, which bend down slightly through the weight of its body, thus exposing both anthers and stigma, and these parts touch the under surface of the insect's body as it thrusts its tongue down to the base of the flower to obtain a sweet fluid (*nectar*) that is produced by small glands situated there.

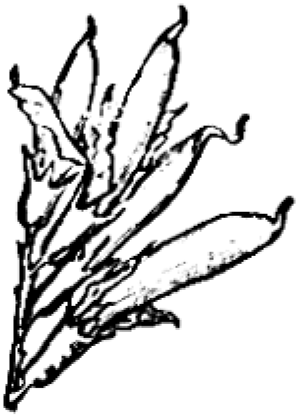

Fig. 68.—The Developing Pods of the Bean.

After a time the corolla begins to fade, and falls to the ground. The stamens soon wither away, as do also the stigma and style, so that nothing is left of the flower except the calyx and ovary. The latter grows rapidly, forming a pod of considerable size; and, if allowed to remain on the plant, it eventually becomes dry, and splits into two valves, exposing several large seeds, the little stalks of which break away, allowing the seeds to fall to the ground. The pod, which is thus seen to be the ripened ovary of the flower, is the *fruit* of the bean; and the *seeds* are the ripened ovules which it contained in its earlier stage.

We now select another flower that has just opened, and carefully cut off its ten anthers before they reach maturity. The flower is now tied up in a bag of fine muslin, while still attached to the plant, so that no insects can approach it, and watched as before. In this one also the corolla, the remains of the stamens, style and stigma all decay, but so does the ovary and even the calyx and stalk, so that no fruit or seeds are formed.

Similar experiments may be tried with other flowers, and all with the same result. Now what do such experiments teach us? Evidently that the pistil and stamens are the reproductive organs of the plant—that both these parts are essential for the reproduction of the species through the agency of seeds. The pistil, since it contains the ovules or "eggs" of the future plant, is spoken of by botanists as the female organ, while the stamens, which are evidently the means by which the ovules are "fertilised" or rendered capable of development, are called the male organs. Thus a flower which possesses both stamens and pistil is said to be a *perfect* or *bisexual flower*, while one that contains stamen only or pistil only is an *imperfect* or *unisexual flower*. Of the unisexual flowers, the former is the *staminate* or *male flower*, and the latter the *pistillate* or *female flower*.

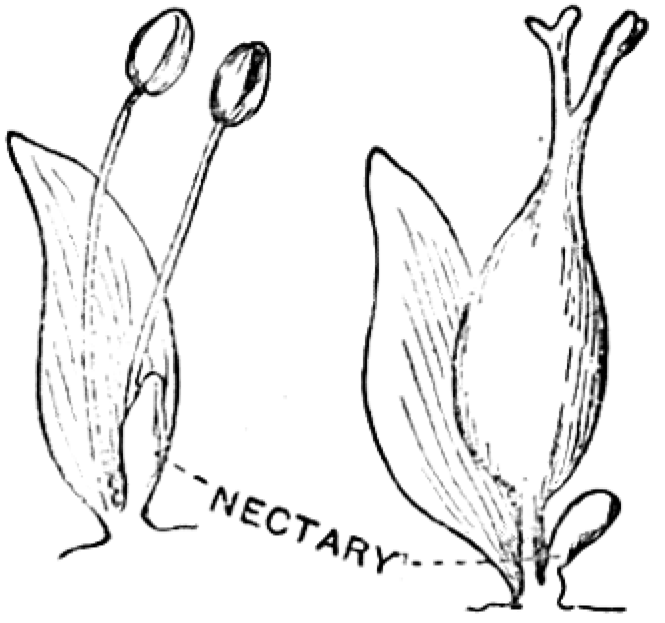

Fig. 69.—Male and Female Flowers of the Willow.

We gather from the above observations that the stamens and pistil, since they are concerned in the reproduction of the plant, are to be regarded as the most important organs of the flower. They are, in fact, the *essential* organs, constituting in themselves the perfect flower, while the parts external to them may be only of a protective nature, or may, as we shall presently learn, perform some subsidiary function in connection with reproduction.

A brief and simple explanation of the meaning of the term *fertilisation*, and the changes induced by this process, may now be given. When pollen grains touch the mature stigma, they are made to adhere by the gummy secretion before mentioned. Here they grow, deriving nourishment from the sap of the plant, and each gives rise to a slender hollow fibre (pollen-tube) which pushes its way down through the style and into the ovary. When the pollen-tube reaches an ovule, it penetrates through a small opening in its double coat, thus coming in contact with a mass of cells that form the *nucleus* of the ovule. One of the cells of the nucleus, much larger than the others, is called the *embryo-sac*, and contains the ovum or "egg-cell," which lies just opposite the small opening in the coats of the ovule. The pollen-tube penetrates into the nucleus, reaches the ovum, and the protoplasm of both pollen grain and ovum become fused or intermingled. The ovum is now said to be impregnated, and the result is that it divides and subdivides into more and more cells, till at last it has developed into the embryo of a new plant, consisting of a radicle or primary root, two primary leaves or cotyledons, and a plumule or young bud from which other leaves may be developed. Thus the ovule becomes a plant in embryo, ready to develop into a new plant as soon as circumstances become favourable to its growth.

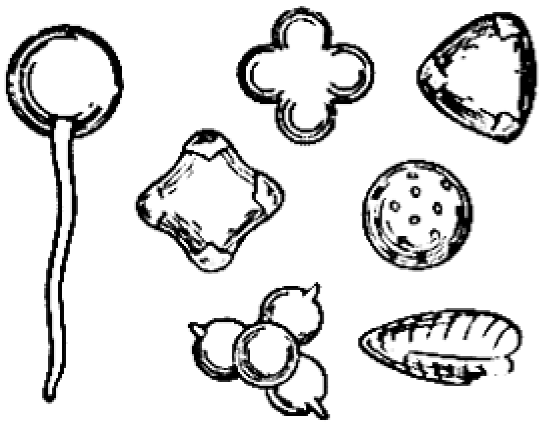

Fig. 70.—POLLEN GRAINS OF VARIOUS FLOWERS, ONE SENDING OUT ITS POLLEN-TUBE.

It is possible that the student may not be able to watch the changes just described, since the preparation of the specimens required for the microscopic examination is beyond the work of the beginner, but he may at least observe the growth of pollen-tubes. To this end, put a drop or two of a solution of sugar on some glass slips, and dust some pollen grains on the solution. Put the slips into a closed vessel to prevent evaporation and examine them from time to time under the microscope.

Pollination of Flowers.

Having now learnt that the transference of pollen from the anther to the stigma is necessary to bring about the fertilisation of the ovules, and knowing that the pollen grains themselves have no power of movement, we must become acquainted with the means by which the pollen is brought in contact with the stigma.

Some flowers may be self-pollinated; that is, the pollen of each individual flower may be received on its own stigma, and in order that this may take place it is necessary that the anthers and the stigma be mature at the same time, and that the construction of the flower is such as to allow the one to touch the other. It is generally easy to tell, from the examination of a flower, whether self-pollination is possible or not, though it must be remembered that certain of them alter in such a manner that self-pollination is possible at one period or stage of their development and not at another. Thus, the stamens of the pimpernel are some distance from the stigma during the day, when the flower is open, but are pressed against it when the flower closes at night.

Observation and experiment have proved, however, that though the result of self-pollination is perfectly satisfactory in some flowers, in many others it results in fewer and less vigorous seeds than are produced by the transfer of pollen from one flower to the stigma of another of the same species. In fact, there are cases in which the flower is apparently killed when its pollen falls on its own stigma.

In many instances self-pollination is quite impossible, either because the stamens and stigma are not mature at the same time, or, if they are, because the stigma is not situated so that the pollen can reach it. Further, it is evident that self-pollination is out of the question when the flowers are unisexual, as in the willow (Fig. 69).

CROSS-POLLINATION.

Thus we are led to consider the means by which pollen is transferred from one flower to another—a process that is termed *cross-pollination.*

In some aquatic plants this is brought about by the agency of the water, the pollen falling from the anthers and then floating on the surface. In such a case the pollen grains are adapted to this mode of transmission; that is, they are either rendered lighter than water by air-spaces, or they are of such a nature that they cannot be wetted, and so will not break through the surface-film. Further, we generally discover certain contrivances on the part of the plant by which the process is assisted.

As an example, we take the case of the popular aquarium plant *Valisneria,* which has unisexual flowers, the male and female flowers being borne on *different plants.* The flowers are always formed at the surface, and the flower stalks are twisted into a spiral in order to allow them to maintain this position even though the depth of the water varies. The female flowers expose their stigmas close to the surface of the water. The male flowers become detached before they open, and float about on the surface, aided by the wind. They afterwards open, exposing their anthers, which are held at such a height that they are likely to touch the stigmas when the male flowers are drifted against the females.

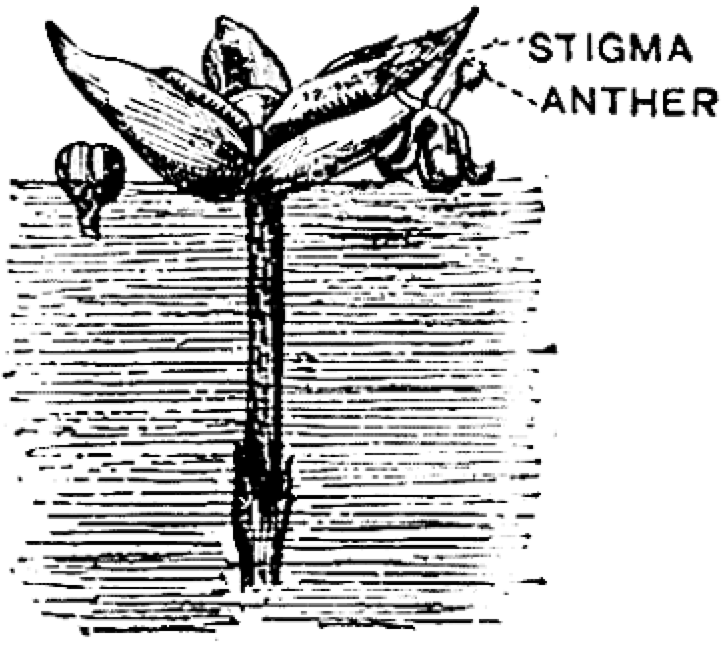

Fig. 71.—FEMALE FLOWER OF VALISNERIA WITH STIGMA EXPOSED. ALSO AN OPEN MALE FLOWER ON THE RIGHT, AND AN UNOPENED ONE ON THE LEFT.

Pollination by the Wind.

Cross-pollination, however, is usually brought about either by the agency of the wind or by that of insects, and it is very instructive to observe how the structures of flowers are peculiarly adapted to their respective methods of pollen distribution. In fact, we can, by the simple observation of the structure and development of a flower, generally say whether it is fertilised by the wind or by insects, and can even, in the case of the latter, often tell what kind of insect would be required to bring about the pollination.

For example, examine the mature flower of the wheat, oat, or any other kind of grass. Note that it consists of a pistil and (usually) three stamens, more or less shielded by chaffy scales (bracts). It has no glands for the production of nectar that would entice insects. The scales spread apart at the time of flowering, thus freely exposing the anthers and stigmas. The pendulous anthers are supported on filaments sufficiently long to bring them well into the play of the wind, and they produce an abundance of pollen grains, so lightly attached that they are easily carried away by the gentlest breeze. The stigmas, too, are freely exposed; and, being of considerable size and of a feathery nature, are admirably adapted for the catching of wind-borne pollen grains.

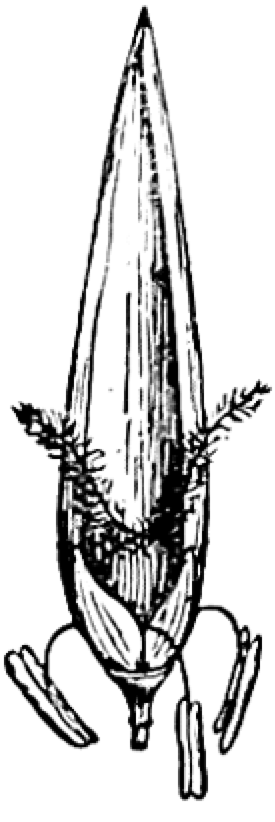
Fig. 72. — The Flower of the Oat.

Our conclusion naturally is that the flowers of grasses are pollinated by the wind, and such conclusion is supported by the fact that we rarely see any kind of insect on them, and especially do we note the absence of those hairy insects to the bodies of which pollen grains would so readily adhere.

As regards the "abundance" of pollen above mentioned, it will be readily understood that, in the case of wind-pollinated flowers, a great proportion of that produced must necessarily be lost by its wide diffusion through the air, and hence the plant, at a distinct disadvantage to itself, is bound to produce much more than would be required were some more direct method of transmission involved.

As another illustration of wind-pollination examine the mop-like clusters of small flowers of the salad-burnet, so common on dry chalky downs, where they bloom from June to August. Each cluster is made up of a dense mass of both male and female flowers, each of which has a calyx of four sepals. The former have many anthers well exposed to the wind on long filaments, and the latter a tufted stigma mounted on a long style. In this case there is also a provision for preventing the pollination of the female flowers by the anthers of the same cluster; for, not only do the female flowers occupy principally the upper part of each cluster, with the male flowers below them, but the latter open later than the former, and distribute their pollen after the females of the same cluster have been pollinated.

For further examples examine—

(1) The flowers of the birch tree (Fig. 73), in bloom during April and May. The male flowers are densely clustered in pendulous catkins, and the female flowers in smaller erect catkins.

(2) The hazel, flowering in March and April. Here, too, the male flowers are in dense pendulous catkins, but the female flowers are solitary, in the axils of the leaves, and hardly to be distinguished from foliage buds until the bright crimson stigmas protrude (Fig. 74). In the hazel flowering takes place before the leaves appear, and thus the flowers are freely exposed to the wind. This is also the case with other wind-pollinated plants and trees.

(3) The flowers of the common great stinging nettle, in the months of June to September. Here the flowers are small and green, and the two sexes are borne on different plants.

(4) The dog's mercury, which flowers from March to May. Here also the flowers are small and green, and the male and female flowers grow on separate plants.

Of course the student will not confine his attention to the few instances given of wind-pollinated flowers, but will endeavour to search out others as opportunity occurs, remembering that such flowers are usually very inconspicuous, and do not develop gaudy perianths to attract

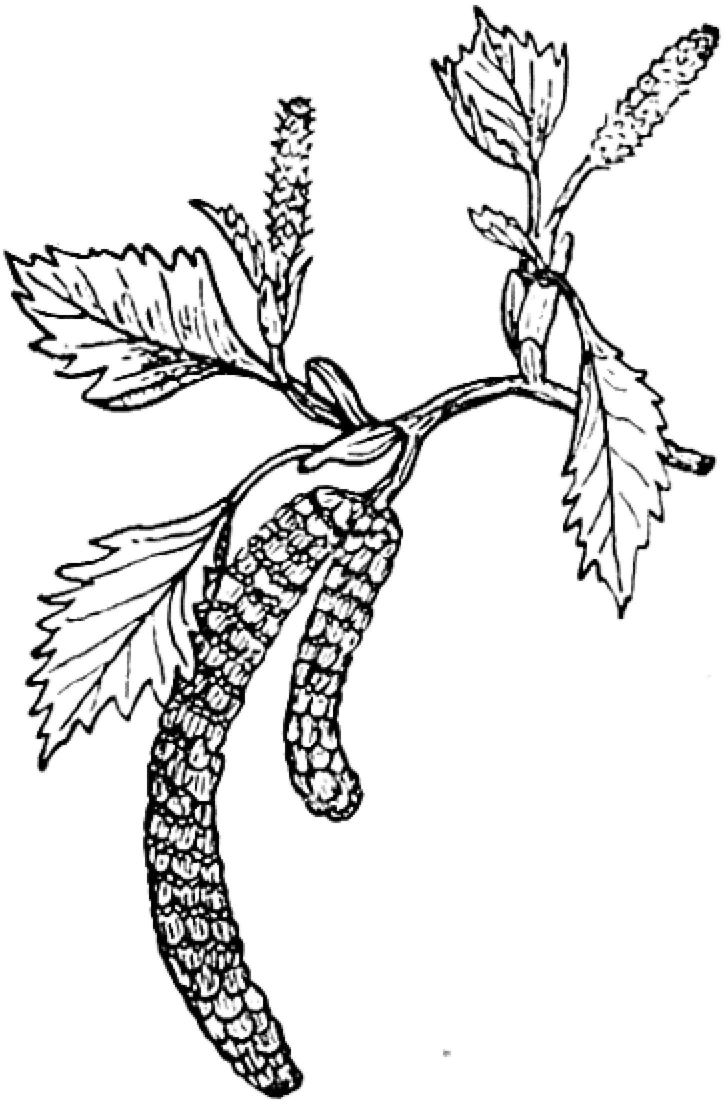

Fig. 73.—Birch.
Twig showing male and female catkins.

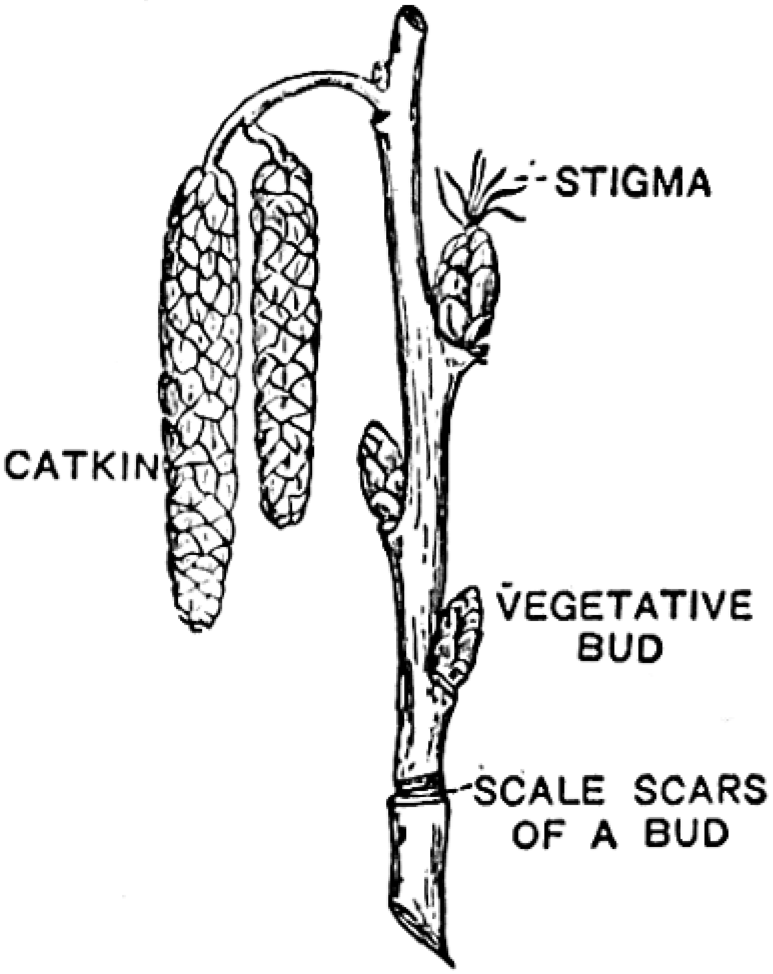

Fig. 74.—Male and Female Inflorescences of the Hazel.

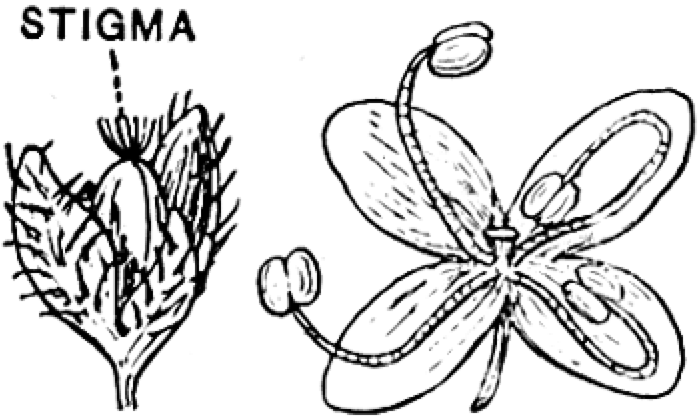

Fig. 75.—Male and Female Flowers of Nettle.

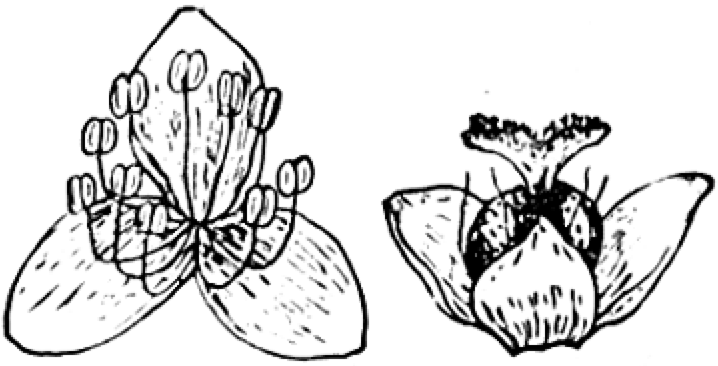

Fig. 76.—Male and Female Flowers of Dog's Mercury.

Examples of Wind-Pollinated Flowers.

insects. They are also mostly very small, and consequently the hand lens will generally be absolutely necessary while studying their adaptations.

POLLINATION BY INSECTS.

Of still greater interest are the many flowers that require the help of insects, and adopt various devices by means of which the insects are attracted and led to give their aid.

First, we return to our typical flower—the bean, and recall its main features as far as they bear on this subject. We have noted that there are nectar-producing glands at the base that provide the food required by so many insects. It has also a very large white corolla which, rendered still more conspicuous by a black spot, is easily distinguished among the foliage, and serves as a landmark to direct the insects to their feast. As an additional signal it emits a very fragrant perfume. It does not produce a profusion of pollen grains, for, as we shall see, it is likely to become pollinated with but little waste of material. It is frequently visited by insects—chiefly bees in this case, and when the insect alights on the lateral petals, bearing them down and thus exposing the anthers and stigma, the hairy stigma is the first to touch the lower part of the body of the bee; and, since the bee has probably previously visited other bean flowers, the hairy stigma brushes from its body some of the pollen that has been carried by it. At the same time the bee's body is pressed down on the stamens, from which it removes pollen to be carried away to other flowers. Thus the bean flower is often cross-pollinated by the agency of bees without any such extravagant loss of pollen as we observed in the wind-pollinated flowers; but it is probable that the flower is also at times self-pollinated, since its anthers and stigma are very close together, and both mature at the same time.

The economisation of pollen is carried still further in some flowers by special habits they have acquired. Thus some of them droop, like the violet and the campanula, and so prevent their pollen from being carried away by the rain. Others require the aid of certain insects, and close their petals to prevent the loss of pollen when these insects are not on the wing. Such flowers are spoken of as sleeping flowers.

The evening primrose is pollinated principally by the aid of the lepidopterous insects (butterflies and moths), and as a much larger number of these fly by night than by day, it closes and protects its pollen by day, but opens at dusk when the moths come out in such abundance. It thus increases its chances of being pollinated, while at the same time it is aided by the attractive nature of its large pale-yellow corolla, which is easily seen in semi-darkness. The day-sleeping flowers that are pollinated by insects have frequently very pale-coloured corollas, and often emit a fragrant odour, to attract the night-flying species. More often, however, do we find flowers that require the aid of day-flying insects, and therefore sleep, and so protect their pollen, at night.

We have seen that the relations between insects and flowers, so far as we have examined them, are mutual—that the insect benefits directly by obtaining food in the form of nectar, and also, in some cases, in the form of pollen, while in return the plant is assisted in the propagation of its species. But it sometimes happens that the insect or other small animal visitor deprives the flower of nectar or pollen, giving nothing in return, and the plant is often modified in such a manner as to prevent or reduce this possible loss.

Some develop a thick covering of hairs on the peduncle. which retards or prevents the climbing of ants and other creeping things. The same purpose is served in the buttercup by the deflexion or bending down of the sepals.

Some, as the columbine, have their nectar stored in spurs of the corolla, so that only those insects with a long proboscis can reach it, while these same insects are, from structure and habit, best adapted to bring about pollination. But wasps and some bees bite through these spurs, and thus rob the flower of its nectar without in any way assisting in the pollination. This kind of loss is reduced in the larkspur by the formation of a double-walled spur, formed by both calyx and corolla. The student should carefully search out and observe such modifications in the structure of flowers, and always endeavour to ascertain what purposes they serve.

We shall now briefly consider in fuller detail a few other insect-pollinated flowers, noting especially the means by which self-pollination is prevented and cross-pollination assisted.

Examine the flowers of the common gorse or furze, which may be seen in bloom all through the spring and summer. They are much like the flower of the bean, and both, together with others of the same order, are said to be papilionaceous or butterfly-like. In some you will find the lateral petals or "wings" of the flower open, with the keel fully exposed, while in others the wings are closed and the keel hidden from view. Observe that bees visit the latter but pass by the former, and the explanation of both the difference in the flowers and in the behaviour of the bees is explained when a bee is seen to alight on a closed flower, for as soon as it rests on the lateral petals, the corolla bursts open with considerable force, and the shock scatters the pollen on the under side of the body of the bee. Another bee will now pass by this flower, for the resting-place is broken, and this seems to be a signal to the bee denoting the fact that the food has been taken. This flower, then, adopts a contrivance to bring about cross-pollination, and its peculiar habit of bursting its corolla economises the time of the bee, and thus secures the pollination of a larger number of flowers.

The common garden sage affords another remarkable example. This flower is one of the labiate or lipped flowers, so called because its corolla has upper and lower lip-like parts. When first this flower opens the stamens may be seen delicately poised in such a manner that when the lower ones (Fig. 77, III. *b*), which are barren, are pushed inwards, the upper pollen-bearing ones (*a*) are made to swing forwards and downwards, so that if you push a piece of straw into the flower, the upper stamens will come down on the straw and dust it with pollen. At the same time the stigma, which is not yet mature, occupies a position close under the upper lip. Thus the flower cannot pollinate itself, but when a bee pushes its head into the flower to obtain the nectar provided, the barren stamens are driven inwards, and the fertile ones are made to swing downwards and dust the insect's back with their pollen. After the pollen has all been removed the style elongates and curves downwards so that the stigma occupies the same position as that assumed by the fertile anthers during the bee's visit, and the stigma now becomes mature. Hence, as the bee passes from flower to flower, some of which have the anthers mature (male stage) and some the stigma mature (female stage), the same part of the insect's body touches the two organs in separate flowers, thus effectually securing cross-pollination with a minimum waste of pollen.

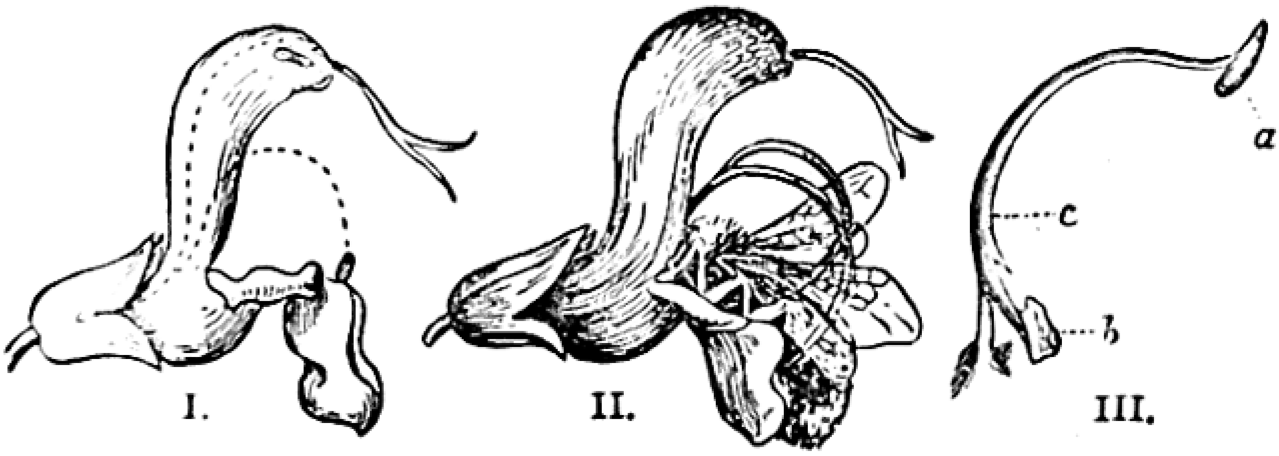

Fig. 77.

I., Flower of Sage (*Salvia pratensis*) from side; II., With humble bee extracting nectar, and the anthers rubbing against his back; III., Single Stamen.

In the flower of the barberry we find the nectaries at the base of the stamens, while the stigma is a sticky ring round the summit of the free ovary. Touch the base of a stamen with a grass stem, and it immediately springs up, being of an irritable nature, bringing its anther close to the stigma. When an insect approaches the nectary, it touches the base of the irritable stamen close by. The stamen then springs up from its former horizontal position, and the anther strikes that part of the insect's body which happens to be near the stigma, dusting it with its pollen.

This same part of the insect's body is afterwards brought into contact with the stigmas of other flowers visited, and thus cross-pollination is brought about.

Now examine the peculiar flower of the cuckoo-pint or wild arum, so common in our hedgerows, where it blooms in April and May. It is of very peculiar structure, varying in so many points from our typical flower that a brief description is necessary. The whole flower is enclosed in a large green and purple leaf which is neither calyx nor corolla, but an ensheathing bract known as the *spathe*. The upper portion of the spathe opens, exposing a bright purple club-shaped mass called a *spadix*, while the lower bulbous portion remains closed except at the top, where it contracts to form a narrow throat. Cut open the lower part, and you see that the spadix is continued downwards, forming an axis round which are situated two clusters of small flowers. The upper cluster is a dense mass of male flowers, each consisting of a single stamen; and the lower is a similar mass of female flowers, each consisting of a single ovary. Above each cluster are some abortive flowers that are reduced to hair-like structures, those above the stamens being longer, directed downwards, and lying in the contracted portion of the spathe. If the flower under examination has recently opened, we find that the female flowers only are mature, but if it is one that has been open for some time, the female flowers are beginning to develop into fruits, and at the same time secrete a sweet fluid, while the male flowers are shedding their pollen. Thus the female flowers are not pollinated by the agency of the male flowers above them, but have by some means become

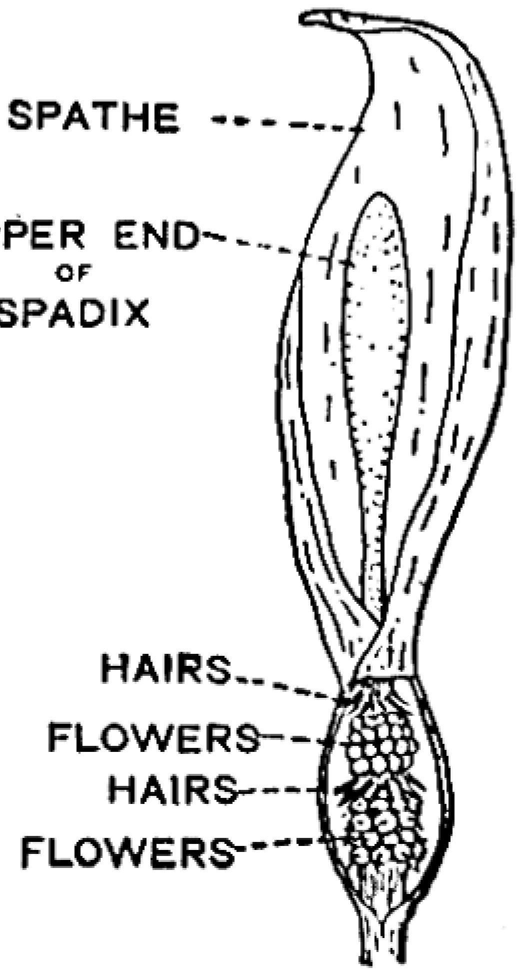

Fig. 78.—The Cuckoo-pint.

fertilised by pollen from another source; and this we shall now attempt to explain.

On opening the lower part of the spathe we always find within it a number of little flies which have been assisted in finding their present abode by the conspicuous nature of the spathe and spadix. All these flies are more or less dusted with pollen collected either here or from flowers previously visited. When the flies visit an arum during its first or female stage, they find no food, and crawl about in their attempts to escape; but they are securely entrapped by the hairs at the neck of the spathe, which hairs, pointing downwards, allow easy access to the interior, but effectually prevent escape. However, in their movements the flies rub their bodies over the sticky stigmas, which are thus pollinated by the grains previously obtained in other arums.

The fertilised ovaries now begin to develop into fruits, and provide nectar to feed the imprisoned flies. The anthers also mature, shedding abundance of pollen grains that again cover the bodies of the imprisoned flies. Then the hairs wither, setting free the flies after the work of pollination has been effected, and after they have become covered with pollen to prepare them for a repetition of the process in other flowers visited.

In the above example it is clear that the female flowers would be pollinated by the male flowers above them if both were mature at the same time, for the former are just under the latter, so that the pollen grains fall directly on them. In the willow, and in some other plants and trees, self-pollination is prevented, even though both male and female flowers are ripe at the same time, by the two sexes being far apart on different plants. Both male and female flowers of the willow are very small, and would not be so readily seen by insects were it not that they are rendered conspicuous by their numbers. Both also produce abundance of nectar, and are visited by numerous bees and flies, as one may judge by the continuous buzzing always to be heard in the neighbourhood of a willow tree on a fine April day.

The primrose provides us with another peculiar device on the part of a plant to secure cross-pollination. We examine all the flowers of one plant, and find in them that the stigma is mounted on a long style which brings it just to the top of the tube of the corolla, and the stamens are attached to the inner surface of the tube of the corolla about half way up. In another plant we note that all the flowers have shorter styles, with stigmas about half way up the tube, and the stamens are at the top of the tube of the corolla; while in both the tube of the corolla is slightly contracted where the stamens are attached. The former is known as the pin-eyed or long-styled, and the latter as the thrum-eyed or short-styled, primrose. It is clear that

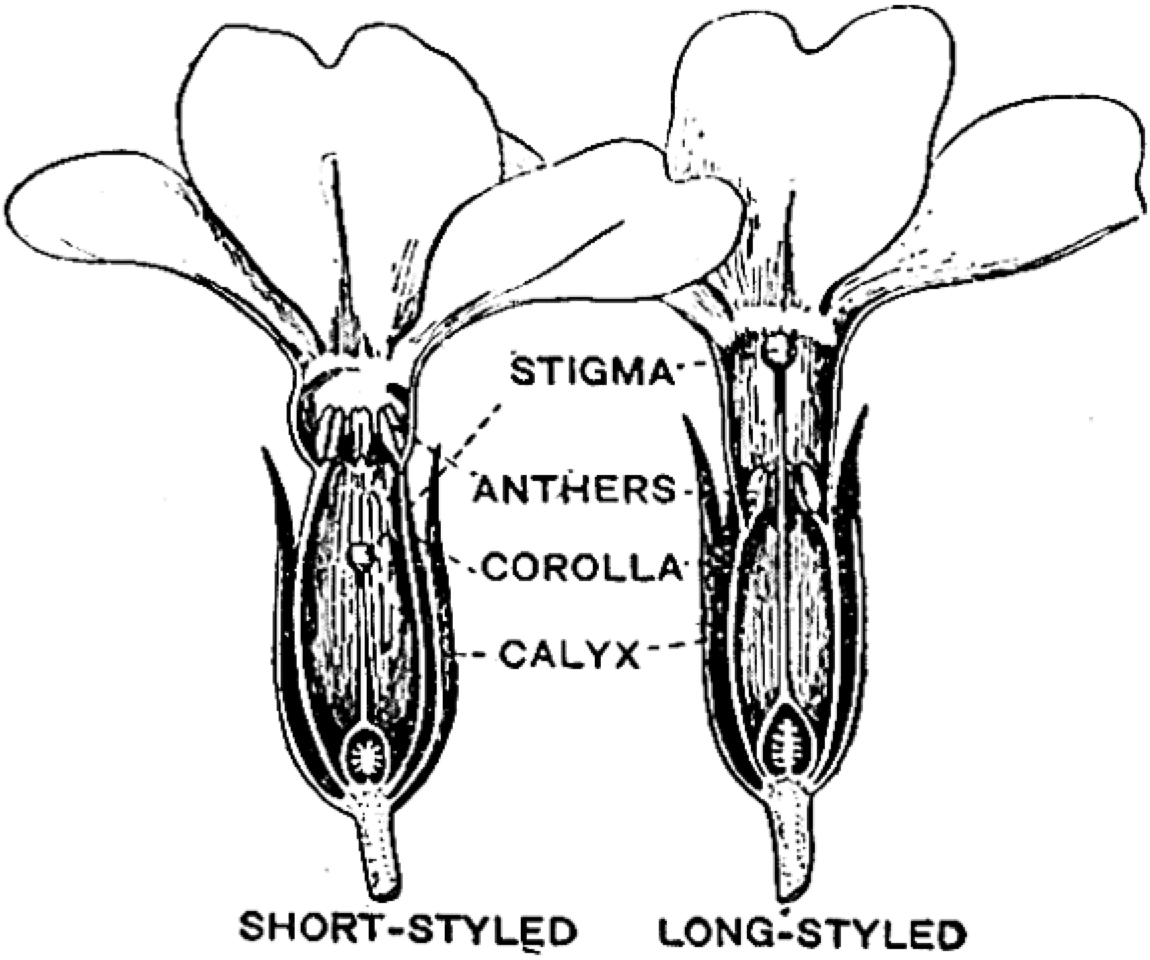

Fig. 79.—Vertical Sections of short-styled and long-styled Flowers of Primrose.

the pin-eyed flower could not pollinate itself, but in the thrum-eyed variety it is possible for the pollen to fall on the stigma. Both kinds, however, secrete nectar at the base of the ovary, and are visited by various insects—butterflies, moths, and some bees and flies—that have a long sucking proboscis. When one of these insects visits a long-styled flower, the base of its proboscis touches the stigma, while the middle portion rubs against the anthers which are brought nearer together by the contraction of the tube. On the other hand, when the insect is sucking its food from a short-styled flower, the base of its proboscis becomes dusted with pollen, while the middle part rubs against the stigma. Thus, as the insect passes from flower to flower, it transmits pollen from the long-styled to the stigma of the short-styled variety, and *vice versâ*; or, in other words, the flowers of one plant are pollinated by the pollen from a different plant.

We can find space for only one other example of the wonderful devices by means of which cross-pollination is encouraged, namely that of the composite flowers, of which the daisy, dandelion and sunflower may be taken as types. In some of these the outer florets are neuter (sexual organs not developed), but the inner florets have an inferior ovary with a long style, and a tubular corolla to which five stamens are attached within. Some have also a hairy *pappus* to represent the calyx.

The anthers are mature first, and as they open the style elongates, brushing upwards the pollen grains by means of the short hairs at its summit. The pollen is then carried away by the bodies of insects that visit the flowers for nectar. Shortly after the stigma divides, exposing for the first time its sticky stigmatic surfaces, which receive the pollen brought by the insects from other flowers. If the florets are not cross-pollinated in this way, it is possible that they may sometimes become self-pollinated, as the two parts of the divided stigma curve downwards in such a

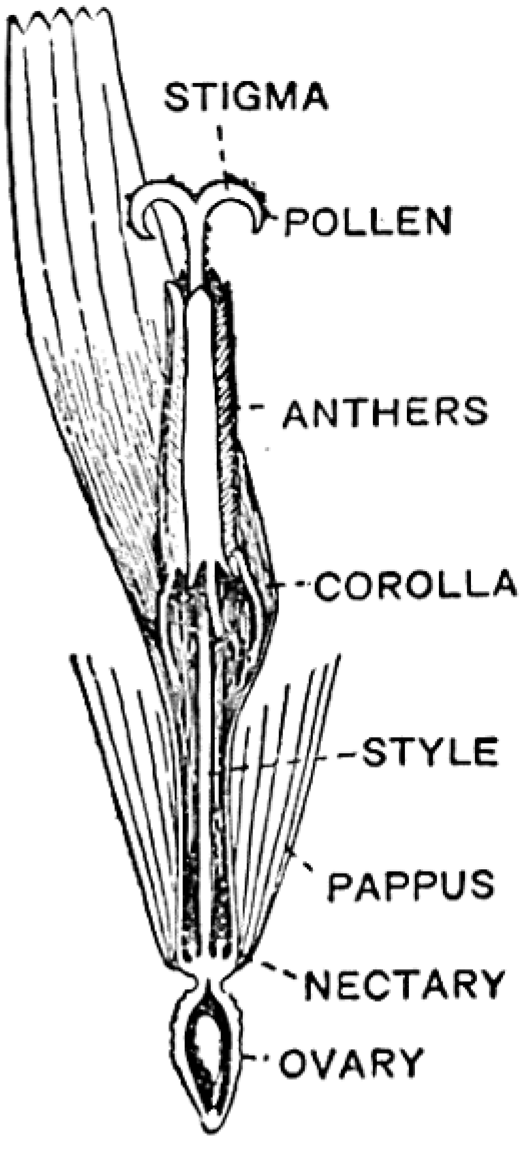

Fig. 80.—Flower of Dandelion.
Basal part cut in Section

manner that they may collect pollen grains not previously removed from the anthers or upper part of the style.

It need hardly be mentioned that flowers can only be fertilised by pollen from the same species, and it is interesting to observe how the insects that afford so much assistance in the work of pollination increase their utility, unintelligently of course, by confining their attention principally or entirely to one particular species of plant on each of their excursions in search of food.

The work of insects in their relation to flowers should be carefully observed by the student, who should also endeavour to investigate, by his own researches, various other ways in which both self-pollination and cross-pollination are brought about by the many adaptive characters of flowers. The few examples taken are intended to serve only as typical guides to direct the student's own observations, and the interest taken, and knowledge gained, in this subject will depend more on the student's own discoveries than on the reading of published examples.

FRUITS.

We have already observed that, after fertilisation has taken place, the ovary develops and forms a fruit, while at the same time the ovules become seeds which contain a plant in embryo. We may, therefore, define a fruit as the ripened ovary, but it must be remembered that other parts of the flower may be persistent, and even become greatly enlarged in company with the developing ovary, so that in many so-called fruits the ripened ovary may form but a small proportion of the whole. This is notably the case with the strawberry, the large succulent mass of which is formed from the central part of the receptacle of the flower, while the real fruits are the little nut-like bodies on its surface.

In the bean flower we observed that the pistil consisted of only one part or carpel. A fruit formed from such a pistil is termed a *simple fruit*. If, however, we examine the flowers of the blackberry in different stages, we find that the pistil consists of several carpels, each of which develops into a little stone-fruit that is united to a prominence of the receptacle. Such a fruit is called a *compound fruit.*

Another kind of fruit may be seen in the lily and the poppy, for in these the carpels are bound together into one compact mass. Still another type is to be found in the hop, for in this case the fruit is not formed by a single flower, but by a cluster of flowers.

The fruits that contain more than one seed generally split open when ripe, thus allowing the seeds to fall to the soil. We shall now examine some of these, which are collectively known as *dehiscent fruits* :—

1. Examine the bean plant when its fruits are ripe. Some have already split into two parts (valves), and the ripe seeds have already severed themselves from their little brittle stalks. Press the edges of the valves of one of the unopened fruits between finger and thumb, and note how readily the valves separate.

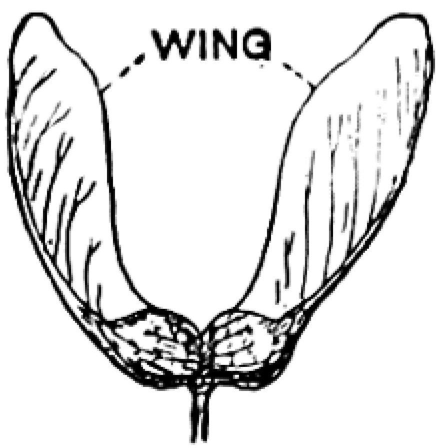

Fig. 81.—Fruit of Sycamore.

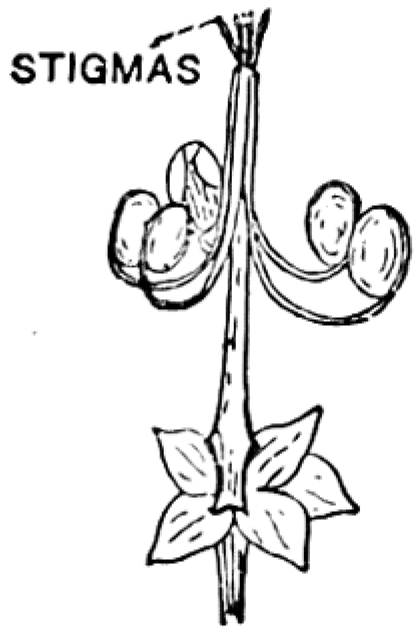

Fig. 82.—Fruit of the Geranium.

2. Pluck the ripe fruit of the hollyhock or mallow, and press it between finger and thumb till it divides. Note that it splits up into many radiating parts, each of which contains a single seed. Other examples of fruits that

split into one-seeded parts may be seen in the sycamore, cow-parsnip, fool's parsley, geranium, etc.

3. Note that the fruit of the larkspur splits by one seam only, and not two, as in the case of the bean.

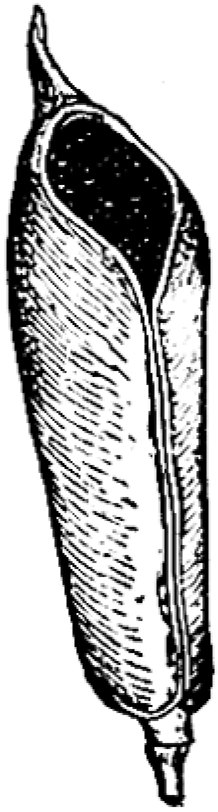

Fig. 83.—Fruit of Larkspur.

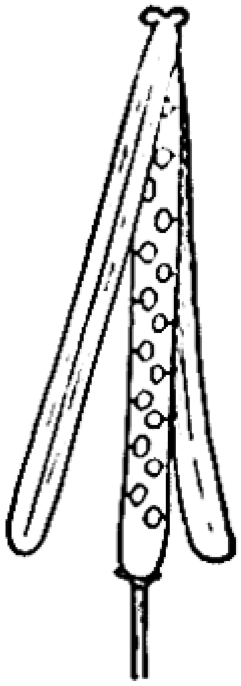

Fig. 84.—Fruit of Wallflower.

4. Apply a gentle pressure to the ripe fruit of the wallflower or stock. Observe that it splits into two valves that separate more readily below, and that the seeds are attached at the edges of a membranous partition

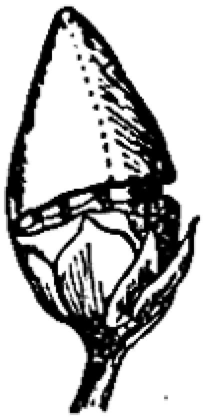

Fig. 85.—Transverse Dehiscence of Capsule of Plantain.

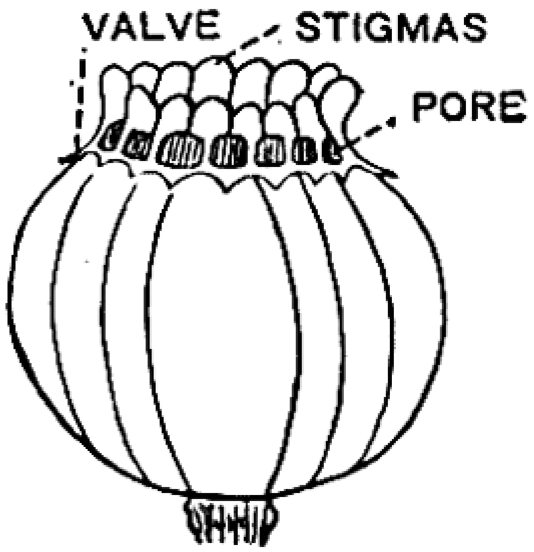

Fig. 86.—Fruit of Poppy.

which divides the fruit into two compartments. Note the similar nature of the fruits of the cabbage and mustard, and the much shorter fruit of the shepherd's purse.

5. Procure the ripe fruit of the pimpernel, and press it gently. It is a globular fruit, and splits readily into two hemispheres; but in this case it divides *transversely*, not longitudinally, as in those previously examined. Note that the little fruit of the plantain splits in the same manner (Fig. 85).

6. As a last example of the dehiscent fruits take that of the poppy. Note that it is formed by the union of several carpels. Make a transverse section of an unripe specimen, and observe that the seeds are attached to the sides of converging plates. Note that in the perfectly ripe fruit a number of pores have been formed at the top (Fig. 86).

We now come to the *indehiscent fruits*—the fruits which do not split when ripe, and which often contain only one seed. Of these we will take a few typical examples :—

1. The fruit of the hazel consists of a nut enclosed in a cupule formed of the united bracts of the flower. The nut itself consists of a hard shell which contains the seed or kernel, surrounded by a thin brown membrane. Compare this with the fruits of the sunflower and the buttercup. These latter are decidedly nut-like, but the outer covering is of a more leathery nature.

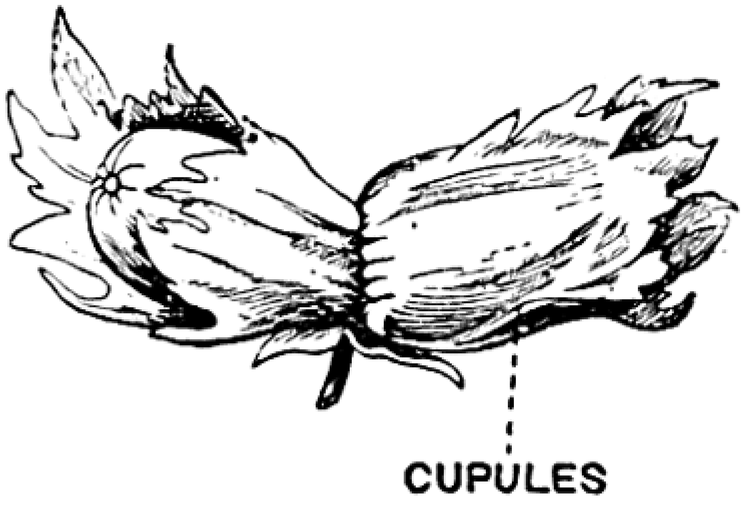

Fig. 87.—Two Hazel Nuts invested by Cupules.

2. Make a section of the cherry or plum. Note the outer enveloping membrane and the thick succulent edible portion in a distinct cavity in which lies the "stone." Break the hard stone, and observe within it the seed or kernel surrounded by a thin membrane. Such fruits are called *drupes*. Compare the cherry with the so-called berries of the holly, elder, and hawthorn. These

latter are compound drupes, and should be carefully distinguished from the true berries. They are formed from pistils that consisted of more than one carpel, each of which gave rise to one stone.

3. Now examine a true berry, such as the grape or gooseberry. It contains several seeds arranged in a soft juicy interior, the whole being formed from a single carpel. The currant, cucumber and tomato are also berries, and their structure should be compared with those already examined. The orange, also, is a multiple berry. It should be noted that the seeds of berries never have a hard "stony" covering.

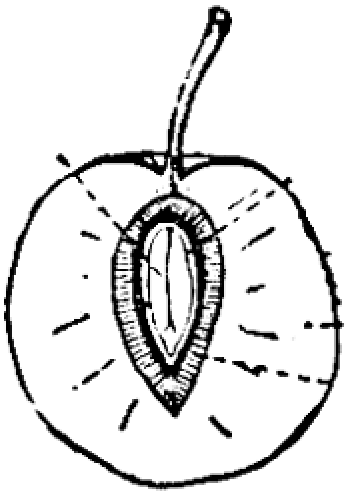

Fig. 88.—Section of the Cherry.

4. As a last type of the indehiscent fruits we take the apple. Note its outer skin, and the thick fleshy edible mass. The latter is not part of the true fruit, since it is formed from the receptacle of the flower. The true fruit is the core embedded within it. A *transverse* section of the apple will show that the core consists of five carpels, each of which contains one or two seeds, and is surrounded by a parchment-like membrane. The pear is similar in structure and origin.

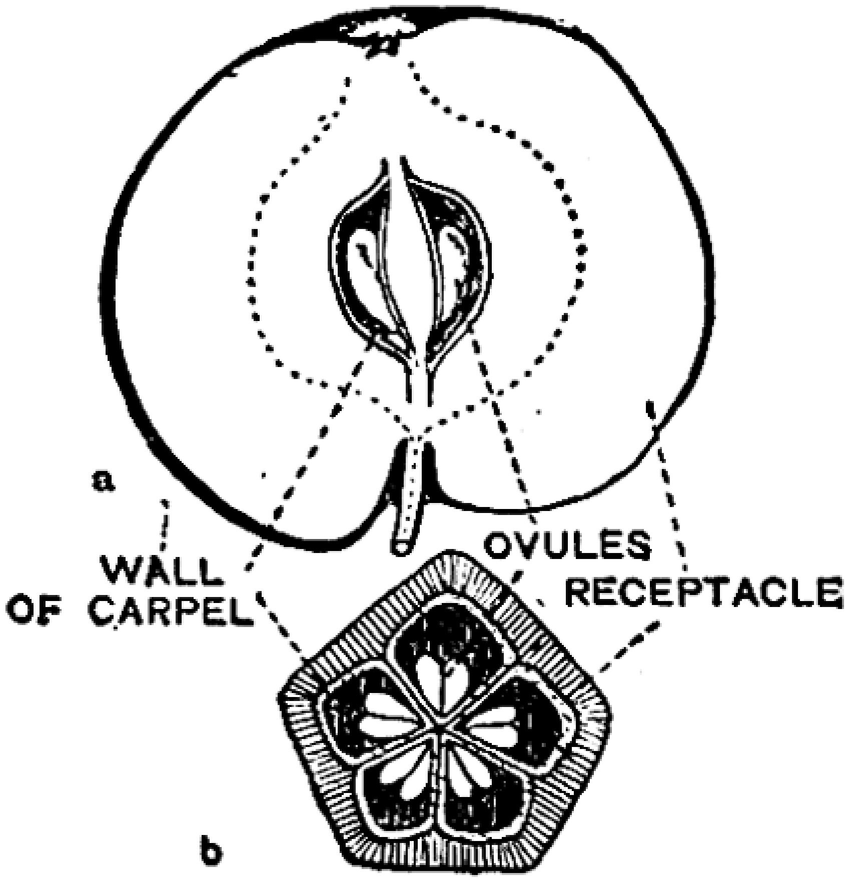

Fig. 89.—(a) Fruit of Apple cut vertically; (b) Young Ovary cut transversely.

We shall now examine a couple of fruits that are of a somewhat exceptional character. The first is the "hip" of the rose, of which we make a longitudinal section. In this specimen the real fruits are the little nut-like bodies that are attached to the outer fleshy envelope; and the envelope itself is the enlarged receptacle of the flower, which has become so concave that it has almost closed at the top. This is an example of what is called an *aggregate fruit.*

Our other specimen is the blackberry, which is also an aggregate fruit. It consists of a number of little drupes or stone-fruits, and as these are removed we find that they are united to a soft mass of tissue that projects upward from the middle of the receptacle.

The number of seeds produced by a single plant is generally so great that, were they all to fall direct to the ground, only a very small proportion of them could ever form mature plants. Imagine, for example, the thousands of sycamore seeds produced by a single tree to fall vertically from the respective branches that bore them. Only a few of these would stand a chance of developing into young trees, and even those few would soon become weak and sickly, not only because the soil is deprived of so much of its available plant food by the extensive roots of the parent tree, but also because of the limited exposure to light and air.

Even in the case of annual plants, which wither and leave the ground clear before the seedlings develop, the young plants would be so crowded and confined that the majority of them would of necessity perish.

Such calamities are greatly reduced by the means adopted by various plants for the dispersal of their seeds; and we must now learn something of the structural peculiarities by which such dispersal is aided, and of the external agencies that take part in the important work. Before doing so, however, we must direct attention to the fact that the dispersal is generally not that of the seed only, but of the complete fruit, and that many of the fruits of plants are popularly spoken of as seeds. Hence the student must be careful to distinguish between the two.

The study of this subject should be carried on out of doors during the summer and autumn. All kinds of fruits should be observed, especially when they are quite ripe and the dispersal is in progress. We shall here be compelled to confine our attention to a few typical examples, but these will be sufficient to serve as a guide for the reader's own observations. The times of fruiting, notes on the modes of dispersal, and sketches of the fruits observed should, in each case, be entered in the student's note-book.

DISPERSION OF FRUITS AND SEEDS.

We shall first deal with examples of fruits that are dispersed by the agency of the wind. There are many such, and interesting lessons may be learnt, especially on a windy day, by smartly tapping plants and tree-branches with a stick when the fruits are ripe.

Many fruits are in themselves very light, and are provided with winged appendages that enable them to be blown considerable distances. As examples, note the winged fruits of the sycamore, hornbeam, birch, elm and ash. In the case of the birch the minute winged fruits may be obtained in hundreds by lightly rubbing a single female

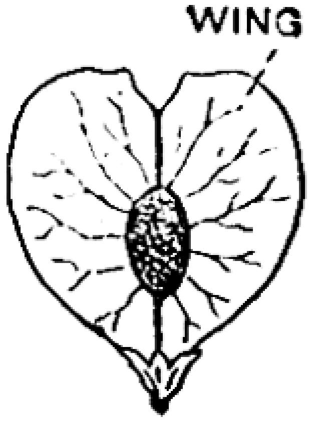

Fig. 90.—FRUIT OF THE ELM.

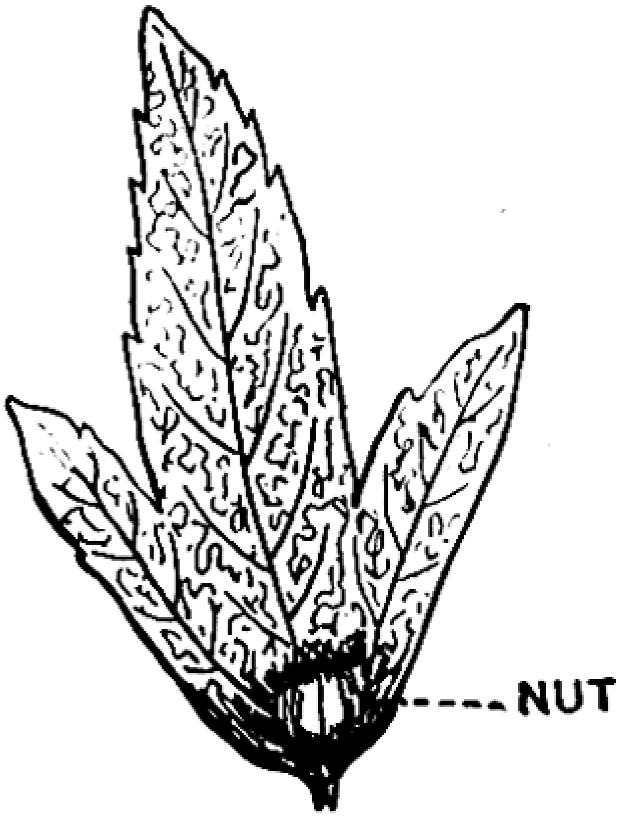

Fig. 91.—FRUIT OF HORNBEAM.

catkin when ripe. The pine cone, when beaten, will yield a number of winged bodies which are *seeds* and not fruits, there being no covering corresponding with the wall of the carpel as seen in most cases.

Some seeds are not distinctly winged, but are flattened, very thin, and light, as in the wallflower. Others are furnished with tufts of fine hairs that serve as sails or parachutes or both combined. Note, for instance, the fruits of the dandelion, thistle and willow-herb. That of the dandelion is often carried miles by the wind during dry weather, and then, as the atmosphere becomes moist, the parachute closes, allowing the seed to fall to the ground, where it is washed in by the first shower of rain.

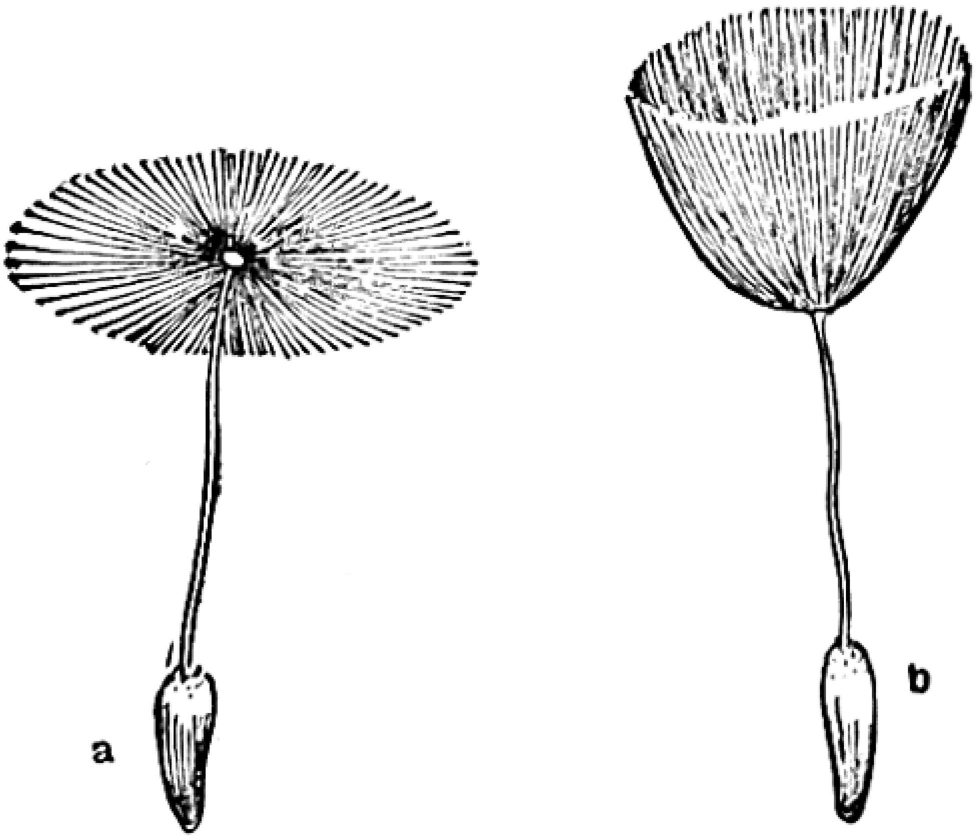

Fig. 92.—FRUIT OF DANDELION.
(a) Parachute expanded, (b) with it closed.

Dispersal by wind involves a very great loss of seeds, such a large proportion falling on sterile soil; hence such seeds are usually produced in great abundance. It is interesting to note, too, that plants producing wind-dispersed seeds do not thrive so largely on the sea-cliffs, where there is danger of the seeds being blown into the sea, as on the exposed downs further inland.

Equally interesting is the dispersal of seeds by the agency of animals. The student must have noticed how tenaciously the hooked fruits of the burdock, goose-grass, teasel, and herb-bennet cling to one's clothing when walking among the herbage; as do also the spined fruits of a large number of grasses. Hence we can estimate the value of the work done by sheep and cattle in distributing these and similar fruits.

It is noteworthy that fruits distributed by this last agency are not produced in such profusion as the wind-dispersed fruits; nor need they be, since the animals which act as the dispersing agents generally carry them to their own haunts, where the soil is usually fertile.

Birds do much to aid in the dispersal of seeds, for they carry succulent fruits to their own haunts, and, after devouring the edible portion, drop the seeds. Often they devour the fruits whole, but in such case the seeds are unhurt, being enclosed in an indigestible covering, and are thus returned to the soil in the excrement. Sometimes birds will devour berries, and the moist sticky seeds liberated cling to their feet, and are thus made to travel considerable distances.

Seed dispersal is carried on to a less extent by the agency of water, though this mode is necessarily confined to those produced by aquatic or semi-aquatic plants and plants of the sea-shore. The seeds of the water-lily are dispersed in this manner, but perhaps the most striking instance is that of the cocoa-nut, which is often carried thousands of miles by ocean currents.

The most remarkable of all the methods of seed-dispersion are certainly those in which the seeds are thrown by the direct agency of the plant itself. On a hot summer's day one may hear on all sides, especially on furzy moors, the crackling sounds of bursting seed-vessels that have gradually become strained, and at last suddenly burst in such a manner as to scatter the seeds, often over considerable areas. In some of these instances, when the fruit is just on the point of exploding, the slightest touch will disturb its equilibrium and enable one to watch the process repeatedly.

The succulent walls of the balsam fruit become swollen and stretched, and a touch of the finger will often cause the strained fruit to explode and throw its seeds a distance of several feet; and the drier fruits of the wood-sorrel, violet and gorse burst with a similar explosive violence. In the wild geraniums there are five one-seeded carpels round a long beak-like axis. The carpels separate from the axis when ripe, and suddenly curl up with great force, shooting out the seeds (Fig. 82).

The fruit of the hairy bittercress is much like that of the wallflower, consisting of two valves and a central membrane. The walls become much stretched when the fruit ripens, and are kept in position by a membrane only just strong enough to hold them together, so that a light touch or a puff of wind is sufficient to break the connection, and then the valves suddenly roll themselves up into a spiral and throw out the seeds. The pods of the broom and some vetches also burst with violence, scattering the seeds in all directions.

The student must search out similar instances for himself, and endeavour not only to observe the manner in which the fruits split, but also to note the direction of the tension which brings about the result in each case.

The Germination of the Seed.

We have learnt that the seed of a flowering plant contains the germ of the offspring, and, in the case of the bean, have seen that young plants develop from them under suitable conditions with regard to warmth and moisture. We did not, however, watch the earlier stages of growth—the germination of the seed, and that we propose to do now.

Soak some beans in water for a day or two, and then remove a few for examination. Note that they have absorbed water and become soft and swollen. Observe the black patch at one end, marking the former position of the stalk which held the seed in the pod.

Wipe all moisture from the surface of the bean, and then press it gently with the black patch still toward you. A little drop of fluid will be seen to ooze through a small opening. This is the same opening (*micropyle*) referred to in speaking of the ovule (p. 83), through which the pollen tube entered for the purpose of fertilisation.

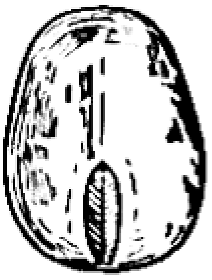

Fig. 93. THE BEAN SEED.

Peel off the outer coat (*testa*) of the bean, and observe its nature. Now note that the seed consists of two large masses of white substance (*cotyledons*) which are quite distinct. Separate these gradually, and note that they are united by another portion of the seed that consists of two parts —a little conical mass (*radicle* or young root) extending just outside the cotyledons, pointing to the former position of the micropyle; and the *plumule* or young bud lying entirely between the cotyledons.

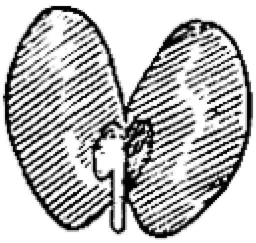

Fig. 94.—A GERMINATING BEAN WITH COTYLEDONS OPENED.

Now transfer the remainder of the beans from the water to a box of wet sawdust, or sow some fresh ones in sawdust. Water them daily, and remove one each day to watch the progress of the young plant. Note that the seed-coat bursts; the radicle elongates, grows downward, and becomes the primary root of the young plant; while the plumule grows upward, bearing a bud, which eventually gives rise to leaves, at its summit. Note, too, that the cotyledons remain under the surface of the sawdust, separate from each other.

As the young plant progresses we note carefully the relative rates at which the radicle and the plumule grow, and watch the formation of their branches and appendages. We observe particularly that the cotyledons or "seed-leaves" gradually lose their firm fleshy nature as

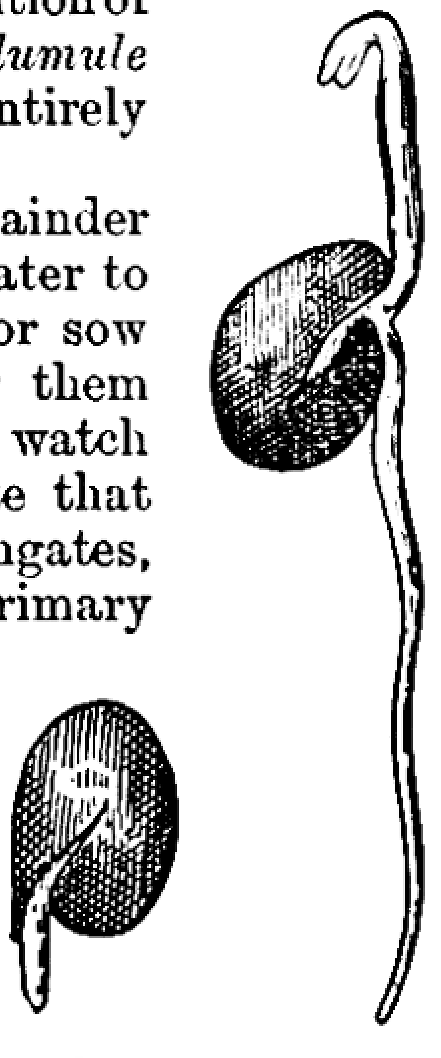

Fig. 95.—THE GERMINATING BEAN—TWO STAGES.

the plant develops, and at last shrivel and die. But their work is now over. They contained a store of nutriment, principally in the form of starch, which supplied the growing plant with food; and this store is sufficient to support the plant until its own roots and leaves have advanced far enough to absorb all that is required from soil and air.

This being the case, we are able to explain how it is that beans grown in sawdust, and supplied with water only, do not reach a stage so advanced as those which are grown in good soil or are supplied with proper mineral food. The former, after exhausting the cotyledons of their food store, although they may, with the aid of their leaves and the chlorophyll, obtain much carbon from the carbonic acid gas of the atmosphere, are unable to obtain the other elements necessary for the building up of protoplasm, cellulose, and other materials necessary for the production of the plant tissues. The student should carefully watch and compare the development of beans or other seeds grown under varying conditions as regards warmth, moisture, air supply, and character of mineral food, and thus become acquainted with the circumstances most favourable to the development of healthy plants.

A very large number of seeds have the same structure as the bean, and develop in exactly the same manner, though in many instances (even in some kinds of beans) the cotyledons do not remain underground, as they do in the case of the field bean, but rise above the soil, develop chlorophyll, and take on somewhat the character of foliage leaves, though they never assume the same form as the latter, and thus may always be distinguished from the true foliage leaves that develop from the plumule. Such seeds are known as *dicotyledonous seeds*, because they split into two cotyledons, and the plants produced from them are called *dicotyledonous plants*. A variety of these should be sown by the student, and the development of the young plants watched and compared. Sketches should be made illustrating the different stages, and the form of the cotyledons compared with those of the foliage leaves. The following may be selected as good typical examples for the purpose:

—Broad-bean, pea, mustard, acorn, lupin, marrow, and sunflower.

Quite another type of seed is represented by the maize or Indian corn, some of which we will now sow in wet sawdust or soil. After having been under the influence of moisture for several hours (a simple soaking in water is sufficient for the present purpose) we remove one or two for examination. Note that the external coat of the fruit (for the so-called seed in this case *is* really the fruit) is easily stripped off, and with it the coat of the seed as well, for in the maize the two are united in their growth.

After the coat has been removed note the small white portion of the seed on one side. This is the embryo of the future plant, and consists of the radicle and plumule, almost surrounded by the cotyledon, while the greater part of the fruit consists of a mass of a pale yellowish colour. Such a seed is called a *monocotyledonous seed*, and the plant produced from it is a *monocotyledonous plant*.

Examine the sown seeds day by day, and note that the radicle grows downward, becoming the primary root, and that the plumule extends upward. While the plumule is still young and compact, a section will show that it is composed of young leaves, the outer of which ensheathe those within.

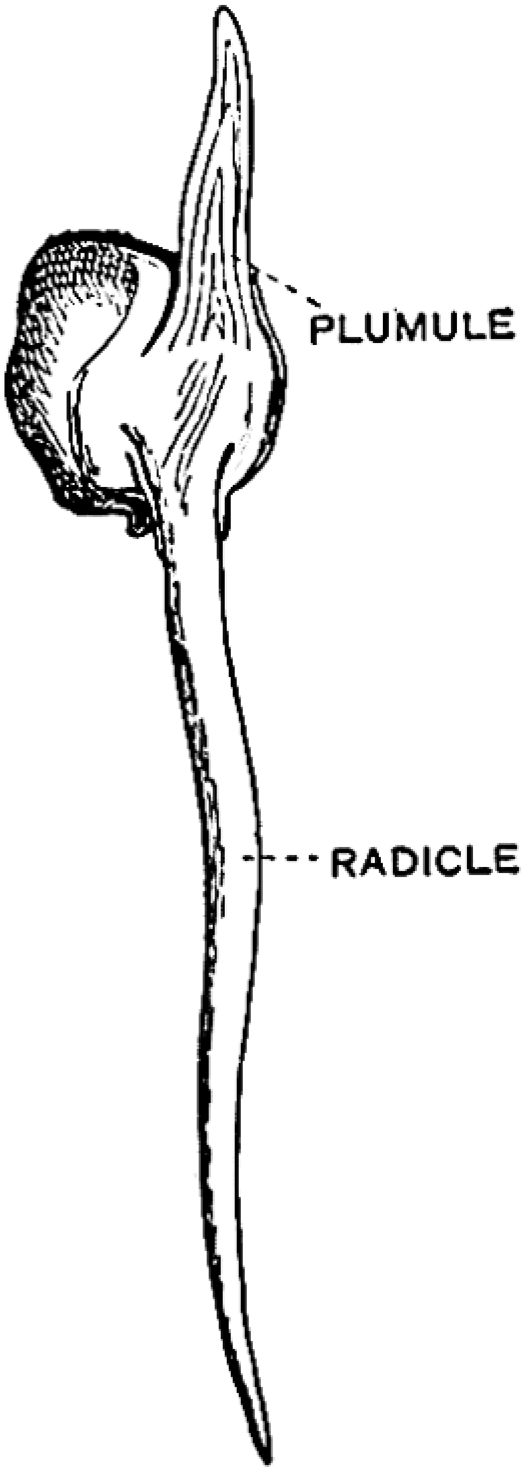

Fig. 96.—Young Seedling of Maize in Longitudinal Section.

At a later stage we observe the lateral roots branching from the first or primary root formed directly from the radicle, and the gradually expanding leaves produced by the development of the plumule. As the young plant advances in growth, we also observe that the single cotyledon, having been deprived of its store of plant food, soon withers away.

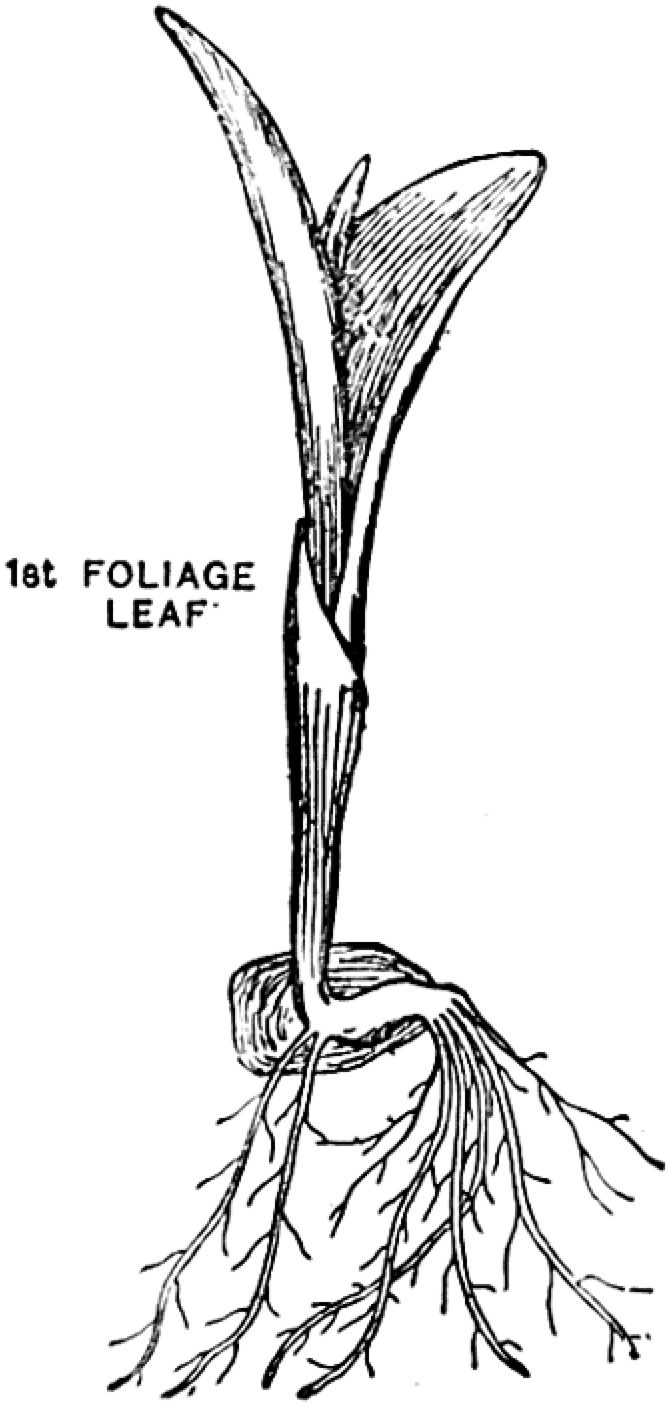

Fig. 97.—Seedling of Maize, later stage.

Other monocotyledonous seeds should be sown, and the development of the seedlings compared with that of the maize. Good examples will be found in the wheat, oat, barley, and the date-stone.

We are now in a position to bring together for comparison certain facts concerning the two great divisions of flowering plants, having observed, more or less thoroughly, the seeds, stems, leaves, and flowers of both groups; and the following summary will recall a number of our past observations.

Monocotyledonous Plants have—

(1) Seeds with one cotyledon.
(2) Stems with no true bark and pith, and the vessels arranged in isolated bundles.
(3) Leaves with parallel veins.
(4) Flowers with parts generally arranged in threes or multiples of three.

Examples—Maize, grasses, lilies.

Dicotyledonous Plants have—

(1) Seeds with two cotyledons.
(2) Stems with bark and pith, and vessels arranged in a ring or rings between them.
(3) Leaves with netted veins.
(4) Flowers with parts generally arranged in fours or fives or multiples of four or five.

Examples—Bean, buttercup, wallflower, etc.

The student should now look over his various notes and sketches of vegetable life in verification of the above statements. He will probably find a few unimportant exceptions, especially with regard to the number of parts in the floral whorls, but these will only serve to emphasize the striking features of the two great divisions referred to.

Buds.

In our former observations of the stems and leaves of flowering plants we have been compelled to give a certain amount of attention to the position and nature of buds, and, before dealing more particularly with this subject, we will briefly summarise the principal facts already learnt. They are:—

1. Buds are young branches which may ultimately bear foliage leaves or flowers, or both.
2. Buds often develop into imperfect branches in the form of thorns or spines.
3. They may be formed either in the axils of leaves (*axillary buds*) or at the summit of the stem (*terminal buds*).
4. The mode of branching of a stem depends on the arrangement and development of the buds it bears.
5. Buds are sometimes formed from roots, as in the hawthorn and apple trees.
6. They are formed, both as lateral and terminal buds, on underground stems.

7. The bulbs of lilies, onions and hyacinths are really buds, formed on a small basal stem.

The development of buds depends very largely on external conditions. Thus, those formed during the summer season soon expand into leaves or flowers, while those formed in the autumn remain dormant throughout the winter, partly on account of the low temperature, and partly because the plant does not receive so much moisture from the soil in cold weather.

Further, many plants produce buds which have but little chance of developing because they are shut off from so much air and light by the crowding of the leaves of the plant itself. For instance, the lateral buds of the horse-chestnut, beech, and other trees are so deprived by the abundant foliage at the tips of the branches. Such buds, however, soon develop and restore the natural appearance of the plant if by accident or otherwise the foliage-laden branch-tips are broken off or damaged. Other trees, such as the birch, have such light foliage that lateral buds can develop freely.

Thus the gardener, by pruning his trees, causes buds to develop which would otherwise have remained dormant; and in some cases, by cutting away the tips of the branches which bear only foliage-buds, he encourages the development of fruiting-buds that occupy a position lower on the stems.

Buds are often formed in abnormal or unusual positions when it would be of advantage to the plant for purposes of growth or propagation. Thus when a tree is cut down new buds are formed on the stump; and these, in producing foliage, save the life of the tree, which, of course, could not exist without leaves. The buds formed on roots belong also to this abnormal or "adventitious" class.

As a bud grows its apex continues to be a "growing-point," thus continuously adding to the length of the branch, and it retains its power of growth even after being severed from the plant, providing it is supplied with the proper food. A bud will often grow if severed from the plant and stood on its base on a piece of flannel kept wet by a nutritive solution, and experiments in this direction should be performed by the student, employing the buds from a variety of plants and trees. Buds grown in this way will often produce new roots at their base, and thus become complete plants.

The process of grafting, so often carried out by the nurseryman, consists in attaching the bud of a plant, together with more or less of the stem, to another of the same species, and in such a manner that the sap of the latter can pass into the former.

In order to study the different modes of branching of stems, which, as we have already seen, are dependent on the varied arrangement and development of the buds, the student should make his observations principally out of doors, as quite a number of different branchings may then usually be seen within a small area.

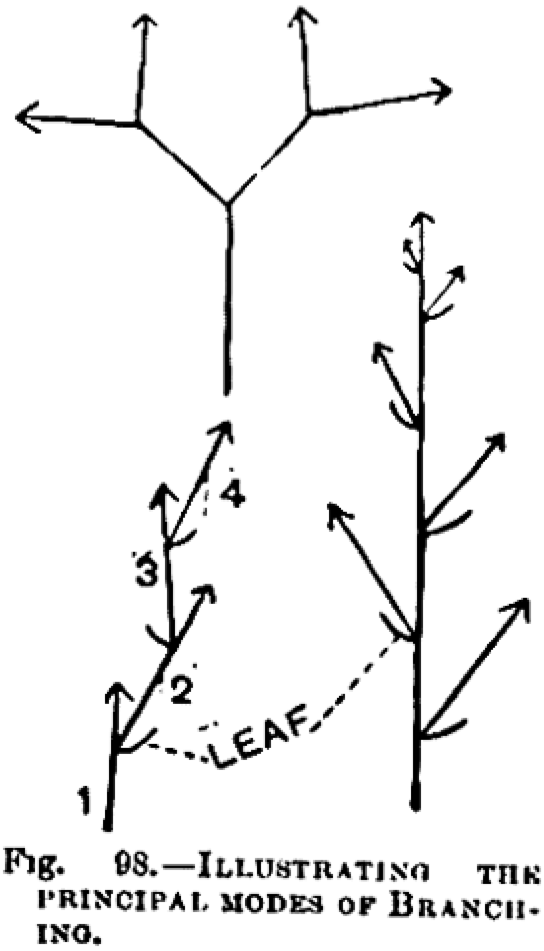

Fig. 98.—Illustrating the principal modes of Branching.

It will be observed that the most common mode is by the development of buds alternately on the stem, as in that kind of inflorescence which we have called the *raceme* (p. 79). Where this kind of branching takes place the terminal bud is continually adding to the length of the main stem, which therefore grows straight. In some plants and trees the terminal bud produces a limited growth, while opposite lateral buds produce strong branches; and modifications are produced when the buds develop on one side only at each node, either alternately right and left, or all on the same side. The student should study these and other modes of branching from nature.

The study of winter buds is especially interesting. The twigs of trees and shrubs should be cut before the buds begin to open. Some of these should be examined both as to external characters and internal structure, and others should be put into vessels of water in order that the development into leaves and flowers may be closely watched. Observations should also be made out of doors in early spring, and the progress of the opening buds should be carefully recorded in the student's note-book, with dates, and the development of each one studied should be illustrated by a series of accurate sketches. Among the various buds especially suitable for our present purpose we may mention those of the horse-chestnut, sycamore, lime, privet, pear, cherry, willow, and the bulbs of lilies and hyacinths.

As regards external structure we must be careful to note the brown enveloping scales, the colour of which is due to the formation of more or less corky tissue, which, on account of its impervious nature, prevents the loss of moisture at a time when the absorption of water from the roots is at its minimum. It will be observed, too, that the exteriors of some buds, notably those of the horse-chestnut, are surrounded by a gummy secretion which still further tends to prevent the loss of moisture. Others, again, like those of the willow, are thickly covered with a dense covering of downy hair which prevents the buds from being wetted, and therefore also guards against that loss of heat which would be caused by evaporation.

It is often easy to distinguish between the buds that will eventually give rise to flowering branches and those which will produce foliage only. The former are usually much more bulky than the latter. In the case of all terminal buds, as well as with many lateral ones, the axis elongates as the bud expands, thus forming a stem which bears leaves; and axillary buds are then formed in the axils of these leaves. These axillary buds may develop into new branches immediately, or they may remain dormant for a longer or shorter period before this change occurs. All such features, together with other observations made by the student, will, of course, be recorded in the series of sketches made.

There remains yet one other point of great importance, viz. the character of the internal structure of the buds as revealed by sections. Select, for the first attempt, the very large buds of the horse-chestnut. Make a longitudinal section through the middle of a terminal bud, and note central axis, the arrangement of the scales and leaves, and the position and arrangement of the young flowers if such exist. A transverse section should now be made, and this will be especially serviceable in showing how the leaves are folded in the bud. Both sections should, of course, be examined with the aid of a lens. Now take a third bud of the same species, and pull off the scales and leaves, one at a time, noting the form, arrangement, and insertion of each part. Other smaller buds may then be selected for a similar dissection and examination, and the differences between them illustrated by simple sketches.

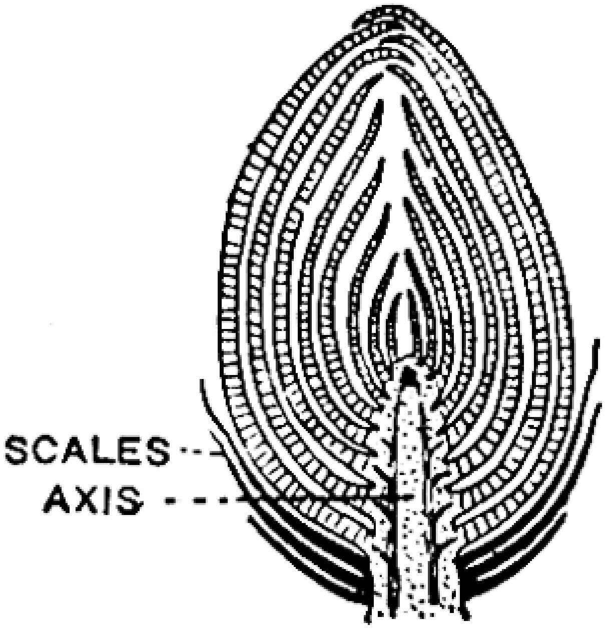

Fig. 99.—Longitudinal Section of a Bud.

Our Forest Trees.

The student of plant life will naturally be led to study the vegetation of his own locality, and since it is impossible, in a small space, to give descriptions for the identification of common plants and trees that would be equally useful in all kinds of localities, we shall, in this concluding section, supply short notes that will enable the reader to identify the commonest of our forest trees, and then recall some of the main local circumstances which determine the character of plant-life.

In the study of our forest trees the student should especially direct his attention to—

1. The general form and appearance as determined by the mode of branching, direction of the branches, and the character of the foliage.

2. The nature of the situation and the character of the soil in which each species apparently thrives with the greatest luxuriance.
3. The general effect of each kind of tree on the appearance of the landscape.
4. The thickness of the trunk as compared with the size of the tree, and the character of the bark.
5. The time of the appearance of the leaves, the form of the leaf, and the arrangement of the veins.
6. The time of flowering and the nature of the flowers.
7. The nature of the fruit and seed and the mode of dispersal.
8. The germination of the seed, and the form of the seedlings especially with regard to the cotyledons.

The following is a list of our principal forest trees, with a few of their principal distinguishing characteristics :—

The Lime.—This tree grows wild in a few of the southern counties, and is consequently sometimes supposed to be indigenous to England; but this is doubtful, since its seeds do not germinate in uncultivated soil. It does not flourish well in the north. The leaves are heart-shaped, with serrated edges. Its flowers, which bloom in June and July, have five sepals, five petals, many stamens, and a globular five-celled ovary with two ovules in each cell. They are of a greenish-yellow colour, and have a long leaf-like bract attached to their stalks. They are also very fragrant and produce abundance of nectar, and are consequently very attractive to insects. The inner bark or bast is in great demand for binding, mat-making and upholstering; and the wood, being soft and close-grained, is largely used by turners.

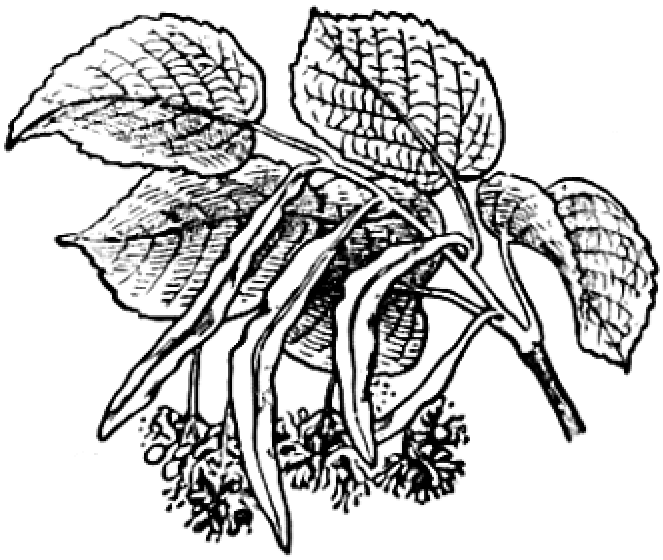

Fig. 100.—The Lime—Leaves and Flowers.

The Sycamore.—The leaves of this tree are usually large, five-lobed, with edges unequally serrate and a palmate venation. The flowers are green, arranged in pendulous racemes, and appear in May and June. The wood is used largely for furniture and toys, as well as for the preparation of charcoal. In Scotland this tree is popularly known as the plane tree. The fruit is represented in Fig. 81.

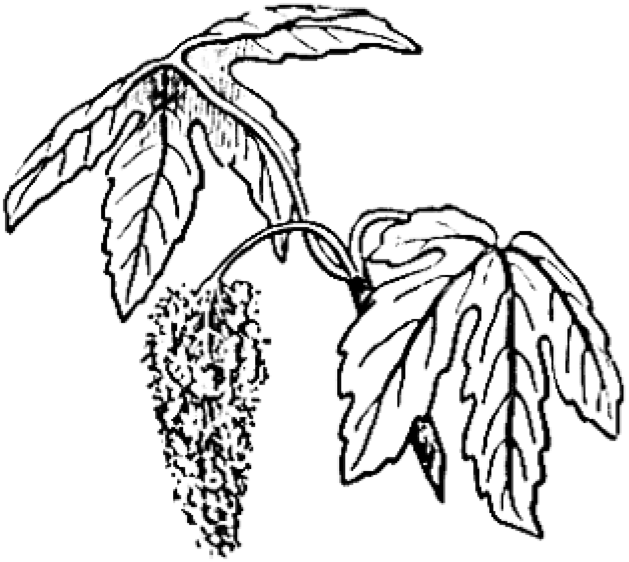
Fig. 101.—The Sycamore.

The Maple is much smaller than the sycamore, and is most commonly seen in hedgerows. It closely resembles the sycamore in the character of its leaves, flowers and fruit, but the leaves have crenate instead of toothed edges, and the floral racemes are erect. The leaves are also rendered conspicuous in the autumn by their rich golden and purple tints.

The Ash.—This tree is of a very graceful form on account of the pendulous nature of the tips of the branches and the foliage. Its leaves are compound, with about five pairs of opposite leaflets and a terminal one. The leaflets are sessile, long and narrow, with serrate edges. The flowers are very small and simple in structure, having neither calyx nor corolla. They are of a dark purple colour, and as they appear in April, some weeks before the late foliage, they are very conspicuous at the tips of the branches. The fruits are winged, and grow in dense clusters. The wood is highly valued on account of its toughness

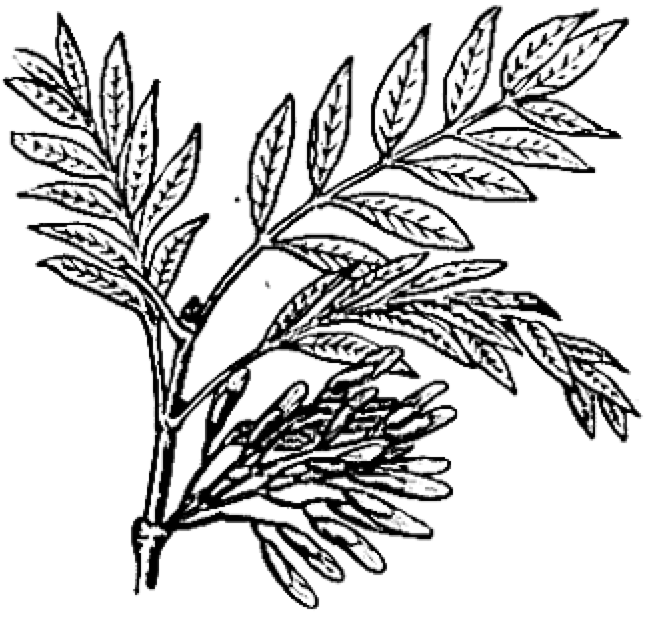
Fig. 102.—The Ash, with a cluster of Fruits.

and elasticity, and is in great demand for the construction of oars, carts, ladders, and farm implements.

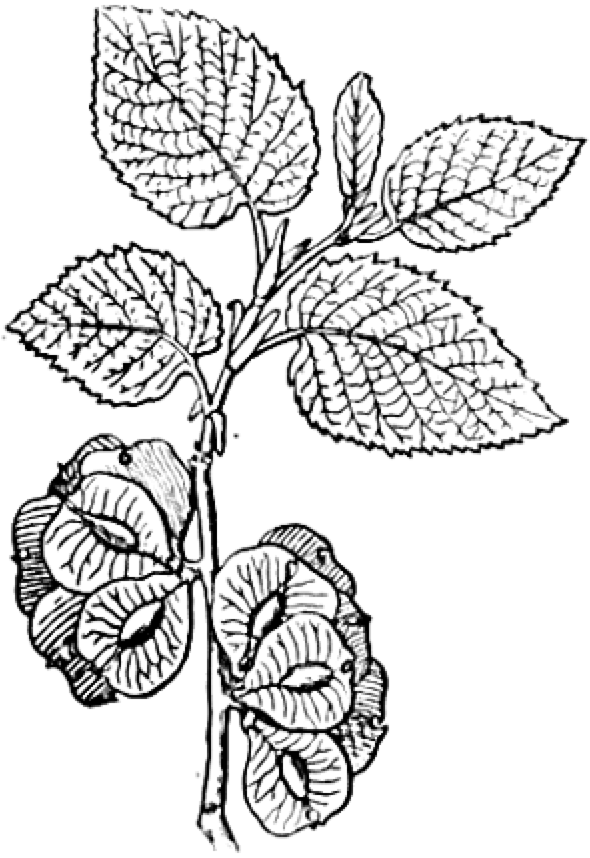

Fig. 103.—THE ELM, WITH CLUSTERS OF FRUITS.

The Elm.—This well-known tree is easily distinguished by its somewhat harsh, simple leaves, which are pointed, serrated, and unequal at the base. In March and early April it is rendered conspicuous by the dense clusters of small purple-brown flowers, which appear before the leaves. Towards the end of April the very thin winged fruits fall in such abundance as almost to cover the ground. The timber is very tough, and, on account of its durability under water, is largely used in marine architecture.

The Oak.—This tree, so well known by its contorted branches, sinuate leaves, and cupuled fruit, need hardly be described. The small greenish flowers should be looked for in April and May. They are unisexual flowers, both sexes being borne on the same plant. The male flowers are in pendulous catkins, with several stamens surrounded by narrow scales. The female flowers are arranged singly or in small clusters, each being surrounded by overlapping scales that eventually form the cupule of the fruit. The tree furnishes very valuable timber, which is largely used for shipbuilding.

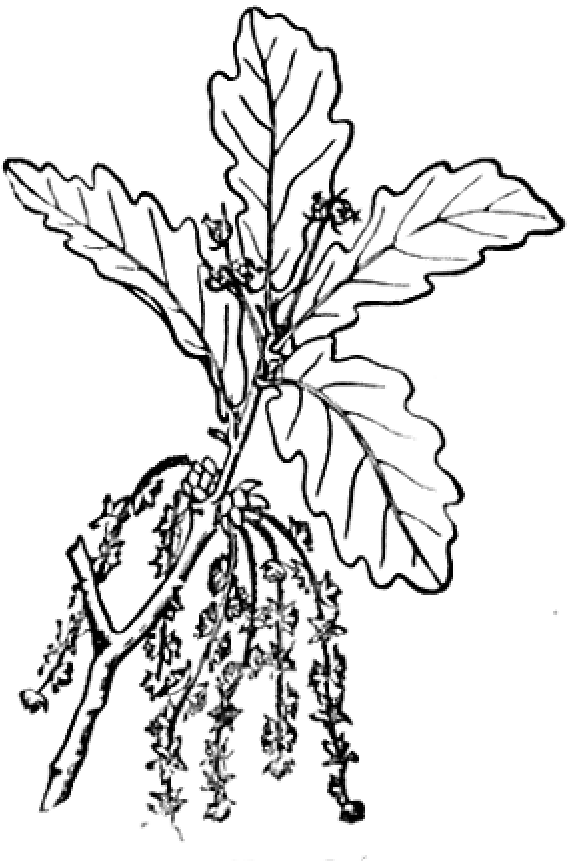

Fig. 104.—THE OAK, WITH FLOWERS.

The Beech is a large and handsome tree, especially when it grows on chalk hills. Its oval leaves are readily distinguished by their smooth surface and hairy margins. The flowers of the beech are very similar to those of the oak, and appear about the same time. The fruit consists of triangular nuts, enclosed in a spiny husk or capsule. The wood is far inferior to that of the oak, but is used for quite a variety of purposes.

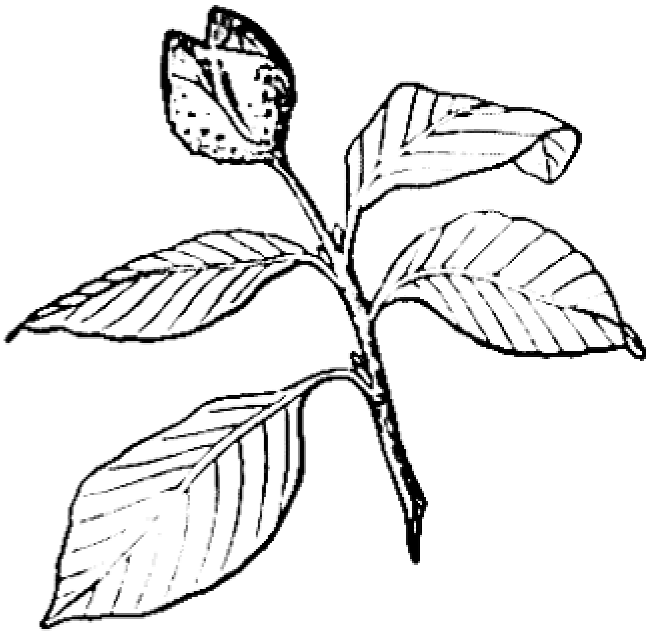

Fig. 105.—The Beech, showing Fruit.

The Hornbeam is usually much smaller than the beech, and is most commonly seen in hedges, but its leaves and flowers resemble those of the beech, though the former are not shiny, and are doubly serrated. The male flowers are in dense cylindrical catkins, and the female flowers in loose catkins. The fruit has one seed, and is enclosed in a lobed bract (Fig. 106), which enables it to be carried by the wind. The wood is heavy and close-grained, but is not much used on account of its tendency to split.

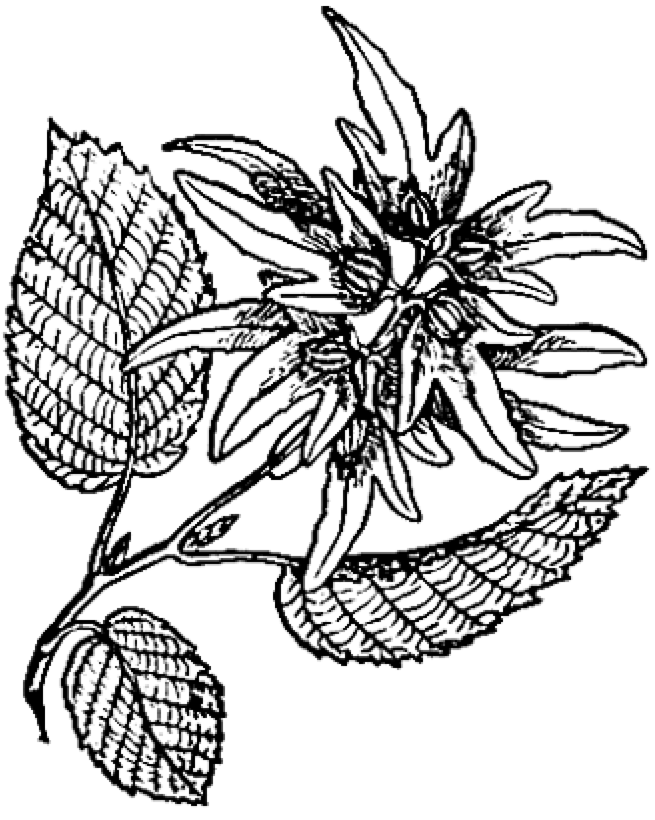

Fig. 106.—The Hornbeam, with Cluster of Fruits.

The Hazel belongs to the same order as the three preceding trees, in all of which the flowers are similar in structure. Those of the hazel have already been mentioned (p. 87), and the fruit consists of a nut in a leafy cupule. Though a small tree, its wood is of good quality, tough and elastic, and is largely used for the making of small articles. It also yields good charcoal.

The Birch is easily recognised by its slender drooping branches and light foliage. Although a slender tree, it thrives well in the bleakest situations. The leaves are rhomboidal in form, and doubly serrated. The erect female and the pendulous male catkins are both represented in Fig. 73. The wood is white, shaded with red; and if grown in cold climates is very durable.

The Poplar. The various species of poplar may be known by the tremulous character of the leaves, due to the flattening of the petioles in a plane at right angles to that of the lamina. They are rapid-growing trees, generally thriving best in moist situations; and, as a result of the rapid growth, the wood is so soft and of such loose texture that it is employed only for the making of packing-cases and other rough work. The poplar flowers in March and April, before the leaves appear. The male catkins are long, pendulous, and of a dark red colour; and the female catkins are conspicuous for the cottony down which envelops the fruit. The scales of the flowers are jagged at the extremity—a feature which serves to distinguish between the flowers of the poplar and those of the allied willows and sallows. The species most commonly met with in our country are (1) *The Lombardy Poplar*, distinguished by its slender and almost perpendicular branches; (2) *The Black Poplar*, with spreading branches; (3) *The White Poplar*, known by the white cottony down on the under side of the leaves; and (4) *The Aspen*, the leaves of which are nearly circular, smooth on both sides, and more tremulous than in the foregoing species.

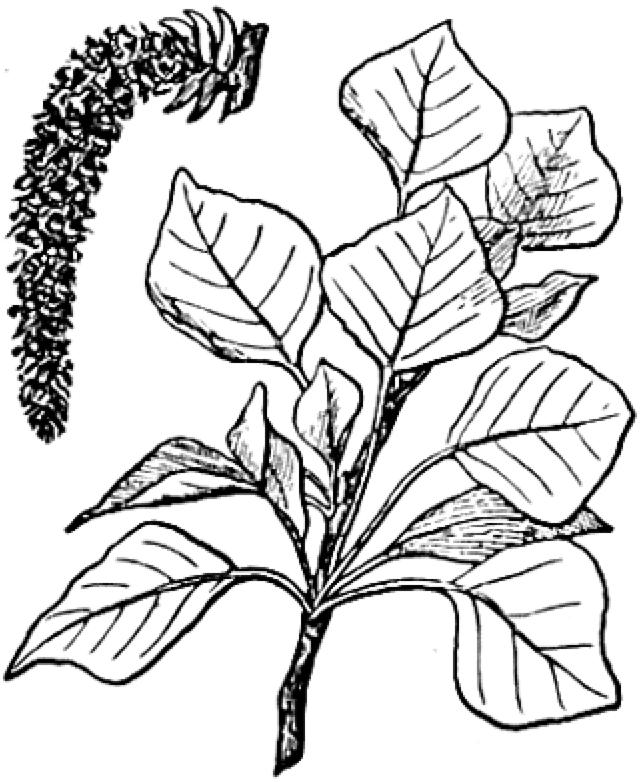

Fig. 107.—The Poplar—Twig and Catkin.

The Willow, as already stated, is allied to the poplar.

It is characterised by the same rapid growth and consequent softness of its wood, and by its still more strongly marked water-loving propensity shown by its frequent occurrence along the banks of water-courses. Its leaves, which are long and narrow, have the same downy under surface so characteristic of most of the poplars; and the seeds are similarly covered with a cottony envelope. The flowers appear in April and May, and are similar in *structure* to those of the poplar, but the male and female catkins are borne on separate trees, and, unlike the flowers of the poplar, produce abundance of nectar. The scales of the flowers also differ in not being jagged at the tip. The *White Willow* is distinguished by the silky whiteness of the under side of the leaves; and the *Crack Willow* by the extreme brittleness of its branches, which break off readily, when bent, close to the trunk. The *Osier*, the young stems of which are so much used for the manufacture of baskets, is a species of willow. The *Goat Willow*, also known as the *Sallow*, may be known by the purplish-brown colour of its branches, and the large broad leaves, which are wavy at the edge.

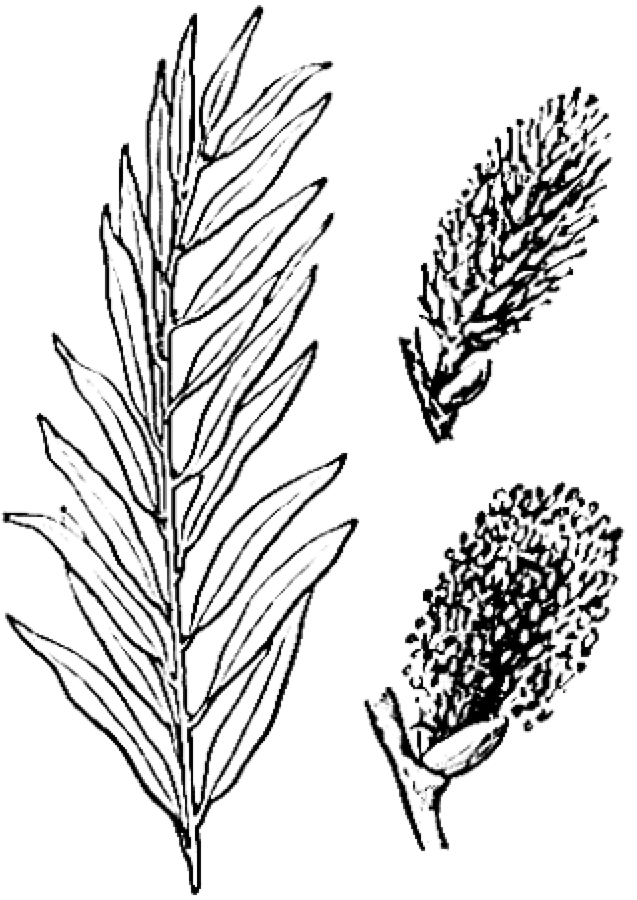

Fig. 108.—The Willow, with Male (lower) and Female (upper) Catkins.

The Horse-Chestnut, though so common in our country, is not indigenous to it. It is so readily distinguished by its large compound leaves, with seven radiating leaflets, that a description for purposes of identification is hardly necessary. Even in winter it may be easily known by its dark heavy branches and large gummy buds; and in the flowering season its erect conical clusters of large white flowers, dashed with pink and yellow, offer a grand spectacle. Although the flowers are not perfumed, they are visited by numerous insects. The fleshy and prickly seed-vessels are full-grown in September, and fall to the ground and split open in the following month. Each fruit consists of three cells, each containing one nut, but usually only one or two of these develop. The nuts are easily distinguished from those of the edible chestnut by the absence of a point at the summit. The tree grows very rapidly, and consequently the wood is soft, with loose fibres, and of little value except as fuel.

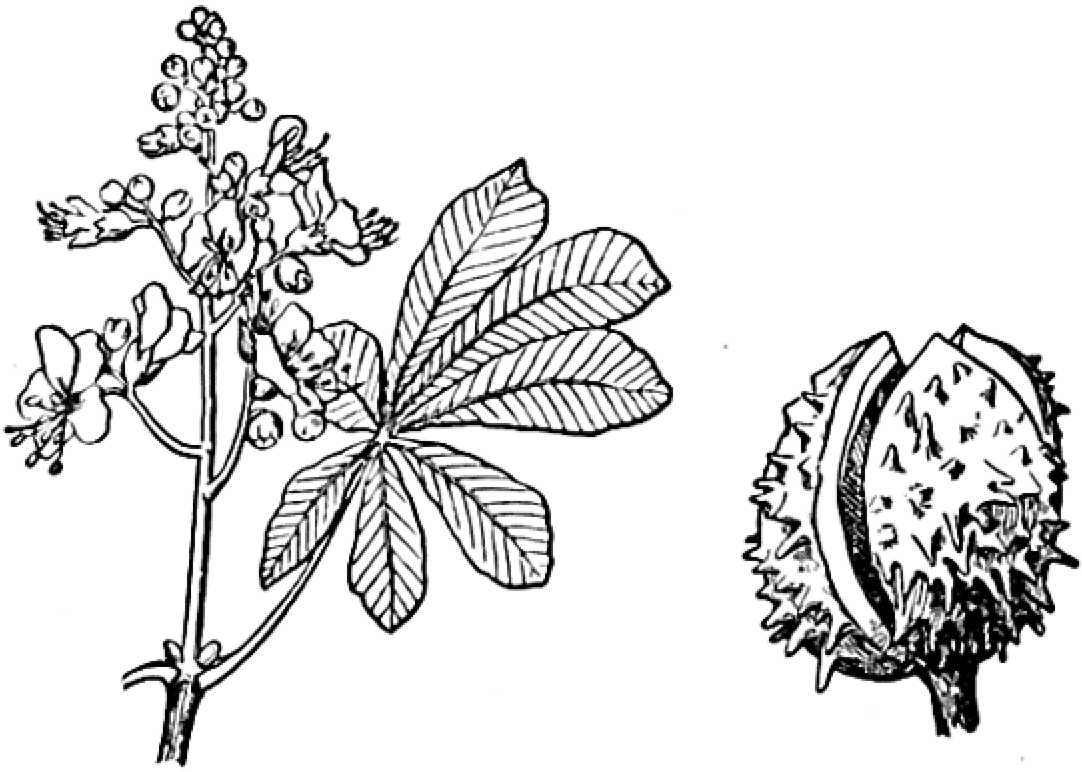

Fig. 109.—The Horse-Chestnut—Leaf, Flowers, and Fruit.

The Sweet Chestnut has long, oval, toothed leaves, which remain on the tree till late autumn, when they assume a rich golden colour. The flowers are produced in long spikes during July, the male flowers being situated on the upper parts of the spike, and the female flowers near the base. The former soon wither and fall, while the latter develop into spiny husks, lined by a silky substance, each containing from two to five pointed nuts, some of which do not fully develop. The fruit is ripe in September, and falls in October, when it splits and exposes the nuts. The young wood of the chestnut is tough, and is used for various purposes; but the older wood is too brittle to be of much service except as fuel. This brittleness is often demonstrated by the ease with which the trees are split during autumn storms.

The Pine may be known by its tall straight stem; long needle-shaped leaves, which are evergreen, and arranged in clusters of two, three, and five, with a sheath of chaff-like scales at the base of each cluster; and by its woody cones, the scales of which are thickened at the top. The pine flowers in May and June. The flowers are unisexual, and both occur on the same tree. The male catkins are clustered round the lower part of the young shoots, forming dense compound spikes, and the flowers consist of overlapping anthers. The female catkins are single or in clusters at the apex of the shoots, and consist of overlapping scales, each bearing two ovules. The latter develop into woody cones which do not ripen until the autumn of the second or third year after flowering, and, when ripe, the naked winged seeds readily become detached from the woody scales. The pine tree is of gregarious habit, forming immense forests in some regions. At high elevations it becomes a mere shrub. It produces very valuable timber, and also large supplies of wood tar and turpentine.

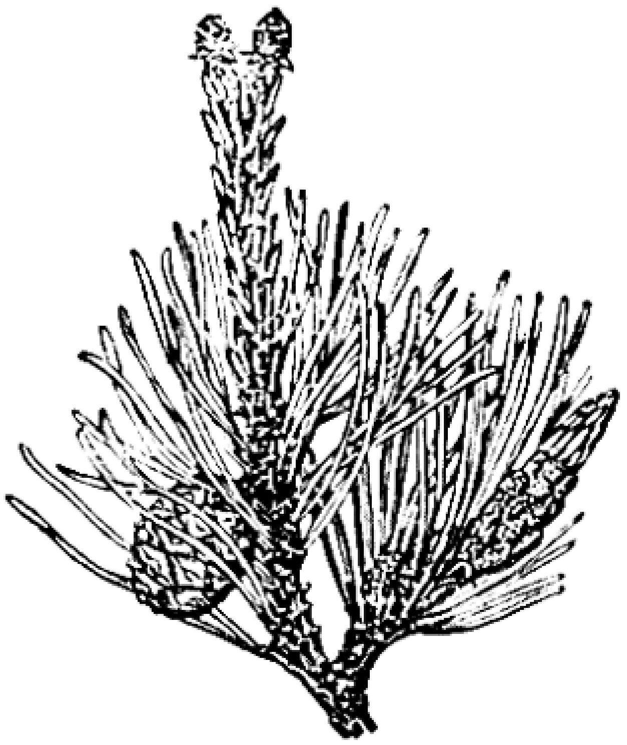

Fig. 110.—The Pine, showing Cone and Flowers.

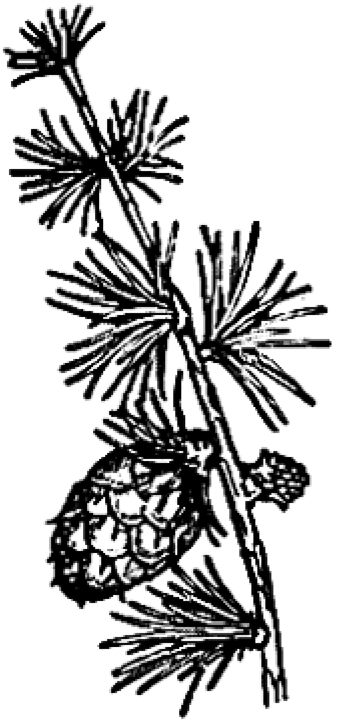

Fig. 111.—The Larch, with Flowers.

The Larch is also a gregarious cone-bearing tree. Its stem is very straight, and its pendant branches give it a pyramidal form. The leaves are needle-shaped, at first in tufts, and then separated by the growth of the shoot. They are small and narrow, and arranged in two rows where they are not tufted. The flowers are unisexual, both sexes being on the same plant. The female catkins form small erect egg-shaped cones, the woody scales of which are not thickened at the tip. The larch provides valuable timber. The trunk also yields Venice turpentine, and the bark is used for tanning.

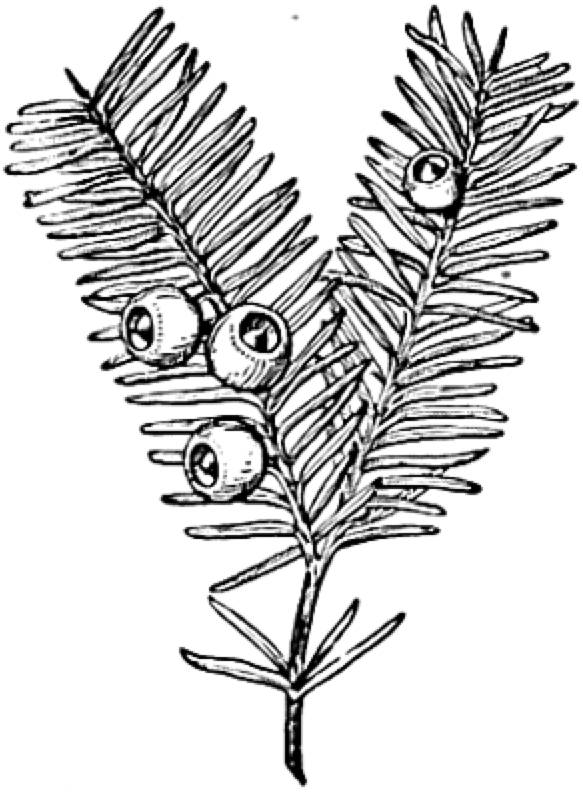

Fig. 112.—The Yew, with Fruit.

The Yew is an evergreen tree with a massive trunk and spreading branches. The trunk has no splitting bark, but looks like a number of stems fused together. The narrow, dark green leaves are shining above, slightly curved, and are thickly set on opposite sides of the branches. The male and female flowers are produced on separate trees, on the under side of the twigs. The male flower consists of a scaly bud with a tuft of stamens projecting above its summit; and the female flower does not produce a cone, but somewhat resembles a small acorn in form, and develops into a red cup-like fruit, containing a small nut the top of which is exposed. The wood of the yew is hard, with fine and close grain, and is also very flexible and elastic.

LOCAL VEGETATION.

We have now to note how the distribution and character of plants depend on local circumstances, and this matter will be briefly considered only so far as it concerns the vegetation of our own country.

First, as regards temperature, we observe marked variations even within the limited ranges of latitude and altitude of the British Isles, for plants that grow luxuriantly on the low ground of the extreme south become more or less stunted in the north and on high ground; and some that retain their foliage throughout the year in the mildest districts of the south and south-west are deciduous in bleaker districts, especially in the north.

In our country, with an average annual temperature of about 50° F., and a marked difference in summer and winter temperatures, nearly all the trees and shrubs, with the exception of the holly and most of the cone-bearing trees, are bare during about half the year, and most of the herbaceous plants are annuals—plants which die completely at the end of their season, and are reproduced in the following year by the seeds they have deposited.

The nature of the vegetation in any given locality depends largely on the amount of moisture in the soil. In dry situations we find plants with hard woody stems, often bearing prickles or thorns. Since the thorns are produced from buds that may otherwise have developed into leafy branches, their production signifies a great reduction in the amount of foliage, and a corresponding diminution in the amount of moisture lost by evaporation into the air. Some of the plants frequenting dry places, however, have thick fleshy leaves in which moisture is stored, and the epidermis, being thick, prevents too great a loss of water by evaporation. Some also have tuberous roots in which water and food are stored.

The plants of moist situations, on the other hand, are usually of luxuriant growth, with abundant foliage, and bear no prickles or thorns. The epidermis of the leaves is also thin, and the stomata very numerous.

In connection with this subject it is very interesting to compare plants that grow in moist soils with allied plants, or even the same species, growing on the dry and sterile cliffs near the sea. Thus, the species of bindweed, milkwort and plantain which are peculiar to the sea-coast have thick fleshy leaves, while the corresponding species of moister inland districts have foliage leaves of a more normal growth. The bittersweet and chamomile sea-side varieties differ in the same way from plants of the same species growing inland. The student should also compare the woody herbs and shrubs of the moorland, such as the broom, gorse, heath, whortleberry and thyme, with the softer and more succulent plants of marshy districts.

The influence of the soil on vegetable growth is very evident to those who are in the habit of observing the relation between the two. Clays are always more or less barren, partly because they are less porous than loams and sands, and consequently less perfectly aerated. They also become so hard when baked by the sun's rays that the root fibres cannot penetrate into them. Pure sands, too, are not very productive, since they cannot hold sufficient moisture for the support of most plants. Some species, however, like the catchfly, thrive well in sandy places, and these often develop a thick epidermis which prevents undue loss of water by evaporation.

Some plants are well adapted for growing in places close to the sea, where the soil is more or less charged with salt. Such are the saltwort, sea-kale and sea-holly. Their roots absorb very little water, and thus the plants avoid an excess of salt; and the small supply of water is often stored in thick fleshy leaves. The amount of leaf area in these plants is usually small, and on this account, as well as because of the development of a thick epidermis, the loss of moisture by evaporation is minimised.

Many of our wild flowers are particularly partial to chalky soils, and of these the rock-rose, columbine, wild mignonette and purple geranium are striking examples. Others, such as the heather, cranberry and crowberry, thrive best in peaty soils, which consist very largely of organic matter.

Aquatic plants are adapted in several ways to their environment. Their stems and leaves are buoyed up by the water, and consequently they need not develop woody tissue for support; hence we find them softer and more succulent than land plants. Some have both submerged and floating leaves, in which case the latter have stomata on the upper side. When floating leaves exist the stem is long and flexible, so that the leaves may always be at the surface even when the level of the water changes; and both stems and leaves are often rendered lighter by air-spaces between the tissues. The water in which they live usually contains much more carbonic acid gas than the atmosphere, the gas being produced by the decomposition of organic matter in the bed. The carbonic acid gas is absorbed and assimilated very rapidly, and thus the plants are of quick growth. It may be mentioned, too, that water-plants are not subject to such extremes of temperature as are land plants, for water has such a high capacity for heat compared with other substances that it becomes heated much more slowly, and takes much longer to cool.

Finally, the distribution of plants is largely determined by the amount of light. Poppies, stone-crop, house-leek and the sun-spurge thrive best in the full glare of the sun, while the wood-sorrel, violets, wood anemone, lesser celandine, wood-strawberry, cow-wheat, and some orchids prefer the shaded woods. Intermediate with these are the plants of our hedgerows and copses, which are usually protected from the direct rays of the sun during a portion of the day.

It will be noticed that most of the plants that grow in woods bloom very early in the spring; for later in the year, when the trees are covered with foliage, they would not receive sufficient light to enable them to produce their leaves and flowers. Many of them store up food in bulbs or tubers during the summer, and this aids them in the early production of leaves and flowers as soon as the winter frosts are over. The early development of the plant is further aided by the deposit of autumn leaves, which, lying on the ground throughout the winter, tend to prevent the loss of heat from the soil. It will be noticed, too, that the leaves of wood plants generally fade very early in the year, as it is impossible for them to continue their functions after the woods are darkened by the foliage of the trees.

QUESTIONS.

1. What is the effect of light upon the direction of growth of stems and leaves?

2. By what experiment would you prove that starch is formed in the leaves of plants only while exposed to light?

3. A green plant gives off oxygen gas when exposed to light and air. Explain this fact, and illustrate your explanation by a simple experiment.

4. Describe the appearance of a shoot which has grown out of a potato in the dark, and account for its peculiarities.

5. Describe the naked-eye characters of the root of a seedling plant, and state the functions of the various parts.

6. Explain why it is that a shoot which is cut off from a plant begins to wither and droop.

7. Describe the structure of the growing point of a root, and contrast it with that of the growing point of a stem.

8. Explain how starch is formed in a potato, and from what source it is derived.

9. Make sketches illustrating the earlier stages in the germination of (1) a bean and (2) a maize seed, and give the names of the parts of the embryo plants.

10. Explain why it is necessary to bank up celery with earth in the later stages of its development.

11. What do you understand by a storage product? Illustrate your answer by reference to instances which you have encountered.

12. Two acorns are allowed to germinate, one in the neck of a bottle full of water, and the other in an ordinary flower-pot. What differences will be noted in the two plants as they grow?

13. Give an account of the changes in appearance in any common leaf during the whole period of its growth. Explain briefly what part the leaf plays in the life of the plant.

14. In an agricultural experiment a number of different manures were applied separately to patches of similar uncultivated mixed grass land. The results were of two kinds: (*a*) The general growth was increased in all the patches. (*b*) The crops had different appearances in the different patches. Comment on these results.

15. The "heart" of a cabbage or lettuce is of lighter colour, sweeter taste, and more tender texture than the external leaves. How do you explain these differences?

16. What is a tap root? Describe and sketch examples of the principal forms of tap roots.

17. Describe briefly the tuber of the potato, the bulb of the onion, and the corm of the crocus, pointing out the principal differences.

18. What is a rhizome, and in what general features does it differ from a root?

19. What are the differences between a thorn and a prickle? Give examples, and state their uses to the plants.

20. Give examples of climbing plants; explain in each case how the plant climbs. What advantage does a plant gain by a climbing habit?

21. Describe the structure of the epidermis of a leaf, and state the uses of the various parts.

22. Through what part of the trunk of a tree does the sap rise? Describe an experiment to prove the correctness of your answer.

23. The trunk of an oak tree, when in full leaf, is sawn all round so deeply as to cut through the sap-wood. State and explain the effect of this operation.

24. What part of its food does a green plant obtain by means of the root? How does the root absorb food?

25. What is the importance of carbon to a plant? From what source does a green plant get its carbon, and how is it assimilated?

26. Describe and explain all the structures you can see on the cut surface of a tree-trunk which has been sawn across.

27. How is it that herbaceous plants which have drooped during a hot day recover their freshness during the night?

28. Describe the structure of any leaf-bud you have examined. What is the usual position in which buds are developed on the stem?

29. Describe the changes which can be observed in the bud of a tree as it expands in the spring.

30. Describe the peculiarities of the foliage-leaf in each of the following plants:—Pea, Bean, Furze and Clover.

31. Describe an experiment to prove that water ascends from the root to the leaves through the woody tissue of the stem.

32. Describe and compare the inflorescences of the wallflower, parsley and daisy.

33. Distinguish between a flower and an inflorescence, and illustrate your answer by examples.

34. A school museum contains, among other things, some dandelion fluff, a dish of peas, a few nodules of garlic, and some hawthorn berries. How could you employ these to illustrate a lesson on plant germination?

35. Explain what is meant by self-pollination and by cross-pollination.

36. Mention three flowers which are not pollinated by insects, and explain in what respects they differ from flowers which are so pollinated. State the means by which the pollination of these three flowers is effected.

37. Give examples of flowers producing honey, and explain where the honey is produced. Of what use is it to the plant?

38. Describe fully any case you may select of cross-fertilisation by the aid of insects.

39. Describe the special arrangements for ensuring the dispersal of the seed in three different plants.

40. Describe and compare the fruits of the strawberry, raspberry and gooseberry.

41. Explain clearly the difference between a fruit and a seed.

42. Name three flowers that grow in woods, and say how they are especially adapted to the situations in which they grow.

43. Give a general description of any one of our forest trees, mentioning particularly the time of flowering and the nature of the fruit.

44. Name, and briefly describe, any two plants which you have seen growing in marshy places.

SECTION III.—ANIMAL LIFE.

CHAPTER IX.

INSECT LIFE:

ILLUSTRATED BY THE CABBAGE BUTTERFLY (*Pieris brassicæ*).

General Structure.

There are three very common British butterflies with white or very pale yellow wings. They are the Large White or Cabbage Butterfly (*Pieris brassicæ*), the Small White Butterfly (*Pieris rapæ*), and the Green-veined White (*Pieris napi*). They are very similar in structure and habit, and although we shall select the first of them for our study of insect life, it should be remembered that many of our remarks will apply equally well to the other two.

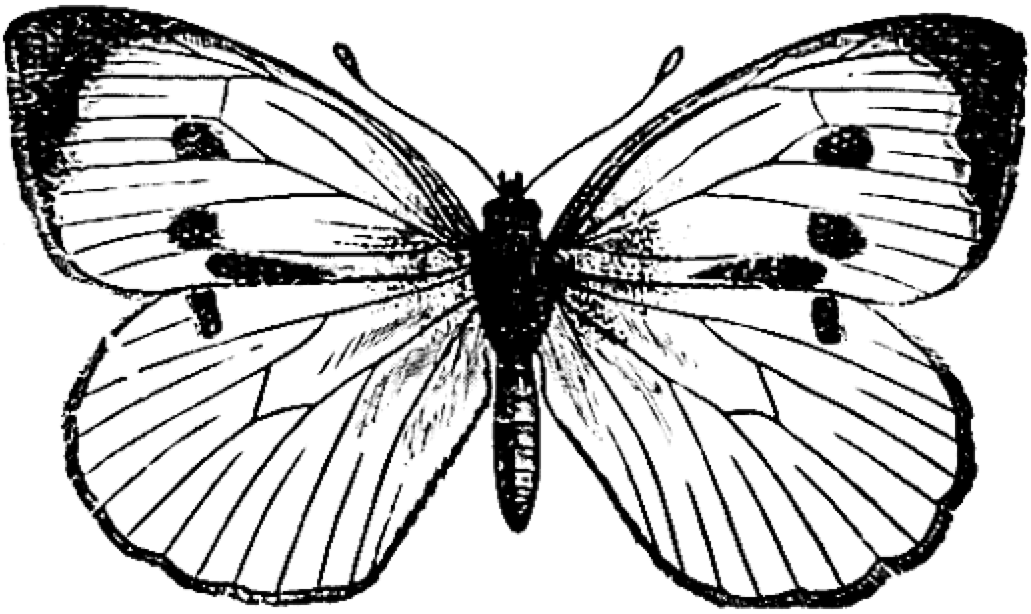

Fig. 113.—The Cabbage Butterfly—Female, Natural Size.

The Cabbage Butterfly may be seen on the wing in all parts of the country during the greater portion of the spring and summer, but is most abundant in April and May, and again during July and August. It may be easily distinguished from the other "Whites" by its superior size.

This insect is easily reared in captivity, and we shall presently give instructions to this end, thus enabling the reader to watch it through all its stages; but for our present purpose we capture one with a large gauze net and examine it closely.

Its body consists of three well-defined parts—the *head*, the *thorax* to which the wings and legs are attached, and the *abdomen*, the three parts being separated by two marked constrictions which we may term the neck and the waist.

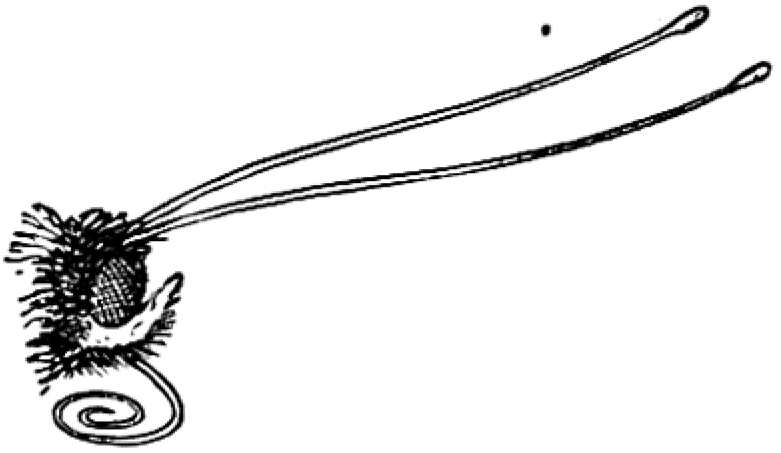

Fig. 114.—Head of a Butterfly, with Proboscis partly uncoiled.

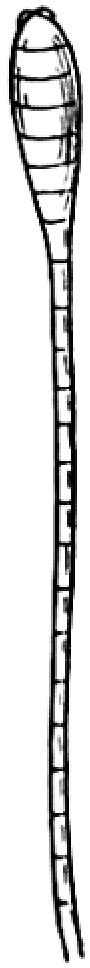

Fig. 115. The Antenna of a Butterfly, Magnified.

The head bears a pair of *antennæ* or feelers which are about half an inch in length, a shorter pair of lip-feelers (*labial palpi*) projecting forward from the under side, a pair of very large eyes, and a *proboscis* or sucking-tube which is coiled into a close spiral and packed away between the palpi when not in use. Each of these must now be examined in turn.

The antenna of a butterfly is moderately rigid, and is enclosed in a hardened skin. It is very slender throughout its length except at the tip, where it is slightly enlarged to form a knobbed or clubbed extremity. When examined with a lens it is seen to consist of a number of ring-like segments all connected end to end. The antennæ of insects are very sensitive. They are not only organs of touch, but they contain rudimentary organs of hearing. It is also possible that they are connected with the sense of smell; and in the case of some of the more intelligent species they serve as a means of communication.

If we examine the eye of the butterfly with a powerful lens we observe that the surface is marked with a very delicate network, the meshes of which are either square or hexagonal in shape, but the full significance of this is only to be made out by the study of a longitudinal section of the organ.

Such a section shows that the eye is made up of a number of crystal-like rods, all radiating from the end of the optic nerve. Each rod is supplied with a filament of the nerve, is surrounded by a mass of dark pigment, and has at its base one of the segments or meshes of the transparent membrane (the *cornea*) that surrounds the whole structure. Each of the little segments of the cornea serves the purpose of a lens, and is capable of forming the image of an object directly in front of it. An eye of this description is characteristic of insects and some other allied creatures, and is termed a *compound eye*.

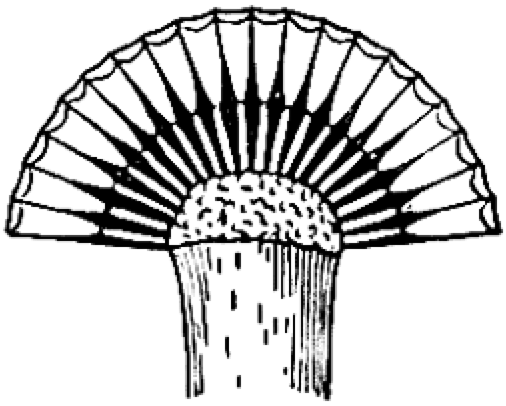

Fig. 116.—Section of the Eye of an Insect, Magnified.

The proboscis of the butterfly is a coiled tube, attached to the under side of the head, in the middle line, between the labial palpi. It is employed by the insect in sucking the sweet juices from flowers and fruits, and one may often get an opportunity of seeing how it is used when observing a butterfly feeding among flowers.

When not in use the proboscis is so snugly packed between the palpi that it is not easily seen, but it may be easily uncoiled with the aid of a needle-point. It is a very interesting object for the microscope, and a low power is sufficient to show that the organ is made up of two half-tubes which are easily separable, and which are normally locked together by means of the closely-set hairs that fringe the inner margins. Further, a transverse section of the proboscis shows that each half-tube has in itself a tube, so that when the two are locked together the organ is traversed throughout its length by no less than three tubes. The middle of these is probably the only one

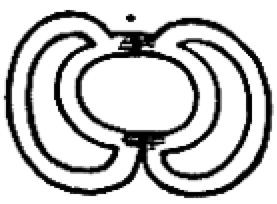

Fig. 117.—Section of the Proboscis of a Butterfly.

through which food is sucked up, and it is possible that the other tubes are respiratory in function, or that they are the means by which fluid passes *down* from the mouth to mingle with any soluble food that is too viscid to be sucked up without such aid.

It will be gathered from the foregoing description that the butterfly has no mouth in the ordinary meaning of the term; that is, it has no opening for the reception of food other than the exceedingly fine tube formed by the proboscis. It cannot take solid food, nor has it any jaws adapted for biting or chewing; but a pair of chewing jaws (*maxillæ*), so well developed and adapted for the reduction of food in some other insects, are here modified into slender half-tubes to form the suctorial proboscis.

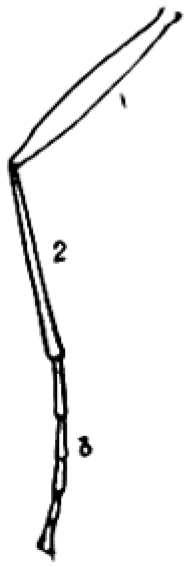

Fig. 118.—Leg of a Butterfly, Enlarged.

1, Femur; 2, Tibia; 3, Tarsus.

The *thorax* of the butterfly consists of three ring-like segments, the divisions between which are not distinctly visible externally. One pair of legs is attached to each segment, and a pair of wings to each of the second and third segments.

The legs are similar in structure, each one being composed of several distinct parts united by moveable joints. The parts are enclosed in a hardened skin, while between the segments the skin is soft and flexible, thus permitting more or less freedom of movement. The first segment of the leg is the *femur* or thigh; and the second, usually the longest, the *tibia*. Then follows the *tarsus* or foot, which is made up of five moveable segments and terminates in a pair of curved claws.

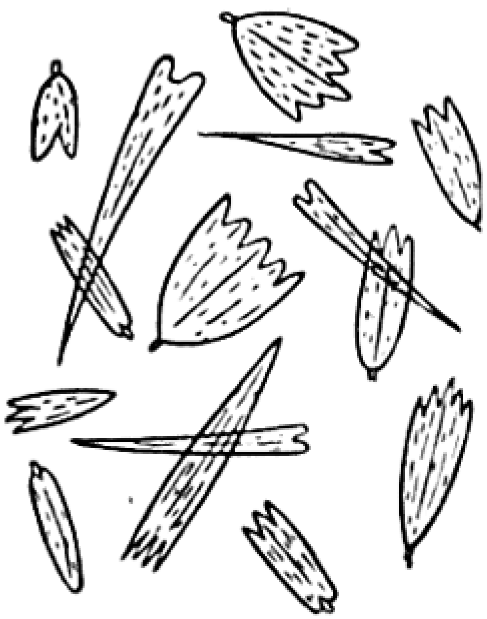

Fig. 119.—Scales from the Wing of the Cabbage Butterfly, Magnified.

If we touch the wing of a butterfly we remove a little very fine dust from its surface. This, when transferred to a glass slip and examined under the microscope, is seen to consist of beautiful little scales variously shaped, and often mingled with fine hairs. Each scale has a short stalk by means of which it is attached to the wing, and its surface is marked by delicate parallel lines.

It will be interesting, too, to observe the scales of the wing *in situ*, and to this end we examine a small portion of the wing under the microscope. The scales are now seen to be arranged in regular rows, attached by their stalks, and they overlap to such an extent that they completely cover the surface on which they are placed.

The colour and pattern of the wing is due entirely to the scales that clothe it, and if we remove all the latter by means of a soft brush we find that the wing so denuded consists of a transparent and colourless membrane, supported and rendered rigid by a system of branching tubes which may be termed the *wing-rays*. These tubes are extensions of the system of air-tubes (*tracheæ*) that penetrate the body of the butterfly for purposes of respiration, and their structure and function will be described later when dealing with the earlier larval stage of the insect.

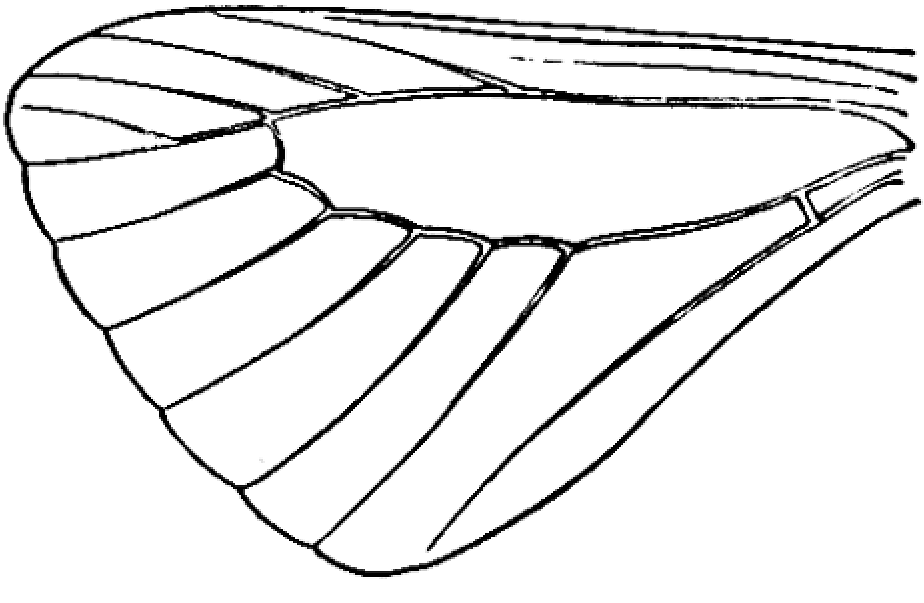

Fig. 120.—Denuded Wing of a Butterfly.

All butterflies and moths have their wings more or less clothed with scales somewhat similar to those we have examined, and it is for this reason that they are placed in a group by themselves and called the *Lepidoptera*, a name which signifies "scaly-winged" (Gr. *lepis*, a scale; and *pteron*, a wing).

EGGS AND LARVA.

The female cabbage butterfly is usually a little larger than the male, and the latter may be readily distinguished by the absence of the black patches on the fore wings, excepting those at the tips. The female lays her eggs on the leaves of the cabbage, "nasturtium," and other allied plants during the month of May, and again in July. The eggs are not deposited freely in captivity, hence the student desiring to trace the complete life-history of the butterfly should set one or two cabbage plants in the garden in the early spring, and he will almost surely find the eggs at the proper seasons, and may even see the butterfly in the act of depositing them.

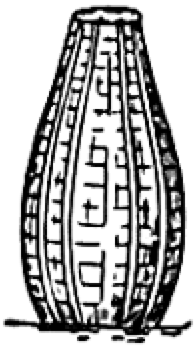

Fig. 121.—EGG OF THE CABBAGE BUTTERFLY, MAGNIFIED.

The eggs are very pretty objects, resembling minute sculptured bottles, with longitudinal ribs and very delicate transverse lines. They are firmly attached to the surface on which they are deposited by a gummy secretion from the body of the insect, and are laid singly or in small clusters.

After a few days, varying from ten to fifteen according to the temperature, little *larvæ* or *caterpillars* issue from the eggs, and, after devouring the shells of the eggs from which they have escaped, commence to feed on the leaf.

The caterpillars should be reared, and observed at frequent intervals, by the student, and this may be done either in the open air or indoors. If the former plan is to be adopted, a cabbage plant on which eggs have been discovered should be completely covered with a muslin or leno net, attached to a hoop of wood or metal that is pressed closely to the soil, and supported by a stick or otherwise

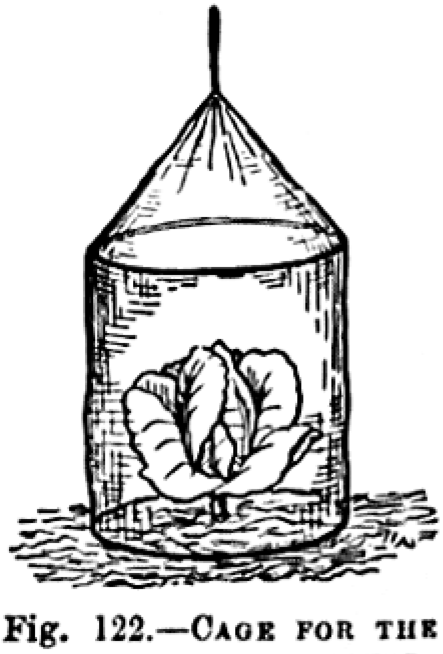

Fig. 122.—CAGE FOR THE PROTECTION OF CATERPILLARS REARED OUT OF DOORS.

at the top. This precaution is advisable not so much to prevent the escape of the caterpillars, which do not, as a rule, leave their food-plant, but to exclude insect-feeding birds and parasitic flies that commit great havoc among the larvæ.

If it is decided to rear the caterpillars indoors a cabbage plant with eggs or young may be transplanted into a tub or large flower-pot; or the caterpillars may be placed in a wooden box in which holes have been made, and over the holes pieces of muslin should be glued. The cover of the box should fit very closely or the larvæ will escape, especially if they are not regularly supplied with fresh food.

The accompanying sketch shows a very convenient form of larva cage suitable for the rearing of almost any kind of insect, at the same time rendering observation easy. It is merely a cylindrical bag of muslin or other suitable fabric, supported by two rings of wire, and fitted with a draw-string at both ends. The lower draw-string passes round the neck of a bottle of suitable size, in which a twig or leaf of the food-plant is fixed in wet sand. Such a cage admits plenty of air and light, and enables one to keep larvæ in a most healthy condition, while fresh larvæ or fresh food can be easily introduced, and all excrement and stale food as easily removed.

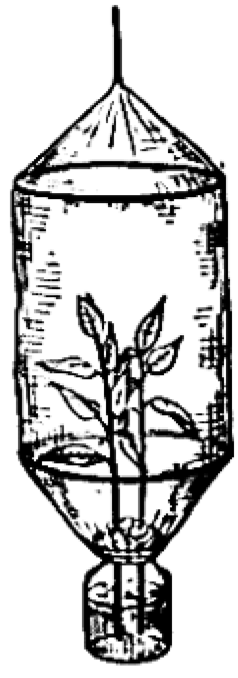

Fig. 123.—A Larva Cage.

The larvæ of the cabbage butterfly are voracious feeders, and grow very rapidly, attaining their full length of about an inch and a quarter in about four weeks, during which time they undergo several moultings or castings of the skin, to be described presently.

For the study of the structure of the caterpillar we select a specimen that is fully grown or nearly so, and examine it with the aid of a hand lens. It is nearly cylindrical in form (Fig. 127), but the body is plainly divided into thirteen segments by very slight constrictions. The first of these segments—the *head*—is narrower than the others, and is partially withdrawn into the second when the caterpillar is at rest. It is also of a bluish grey colour, while the ground colour of the rest of the body is bluish green.

Three yellow stripes, with somewhat indefinite margins, run along the whole length of the body, excluding the head. One of these passes along the middle of the back, and the other two are at the sides. In the spaces between these stripes there are numerous small black spots, each with a little projection bearing a single hair.

The first segment or the head is covered with a hard horny skin. A black mark passes down to the middle of the face, where it divides into two, with a yellow patch between just over the mouth. The mouth is provided with a pair of biting jaws, placed one on each side, and therefore working horizontally. A pair of very short antennæ may also be seen with the aid of a lens; and the low power of a compound microscope will reveal a cluster of six little eyes in a black patch on each side of the mouth. The student should observe the movements of the jaws, with a lens, while the caterpillar is feeding.

Another feature of the head of the caterpillar is the *spinneret*—an organ by means of which it can produce silken threads. It consists of a little perforated tubercle at the lower part of the head, supplied with a viscid secretion prepared by a special gland. When the spinneret is applied to any surface and then withdrawn, an exceedingly fine liquid thread is produced, but this immediately solidifies on exposure to air.

The remaining twelve segments have now to be examined, together with their appendages and other essential features. These segments are all very similar in form and size, but differences are to be observed in other respects.

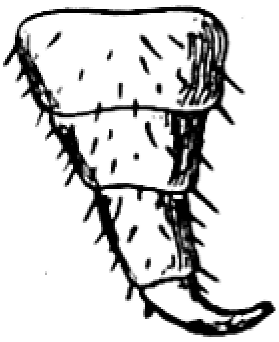

Fig. 124.—Leg of a Caterpillar, Magnified.

The second, third and fourth each bears a pair of legs which are composed of three segments surrounded by a hardened skin, and which terminate in a sharp claw. Segments five and six of the body bear no appendages. The next four—segments seven, eight, nine and ten—bear each a pair of *pro-legs*, which are soft and membranous extensions of the body. These pro-legs are cylindrical in form, not jointed, and are more or less retractile. They terminate in a broad disc round the edge of which is a circlet of minute hooks, by means of which the caterpillar is enabled to cling firmly to any rough surface. Segments eleven and twelve have no appendages, while the thirteenth has a pair of *claspers*, closely resembling the pro-legs in structure, and so called because they so very effectually surround and clasp the stem or other object on which the caterpillar is resting.

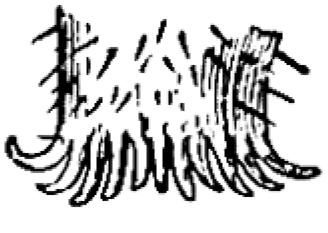
Fig. 125.—Pro-leg of a Caterpillar.

On carefully examining the yellow stripes along the sides of the body we find in them a series of small holes forming a single line on each side. These holes are not to be seen in all the segments, but one may be observed on each side of segments 2, 5, 6, 7, 8, 9, 10, 11 and 12. They are termed *spiracles*, and are the openings of a system of breathing tubes called *tracheæ*. The tracheæ pass inwards from the surface of the body, and divide and subdivide into a complicated system of communicating air-tubes that penetrate every part of the interior. It is by means of this system that the caterpillar is supplied with the air necessary for respiration.

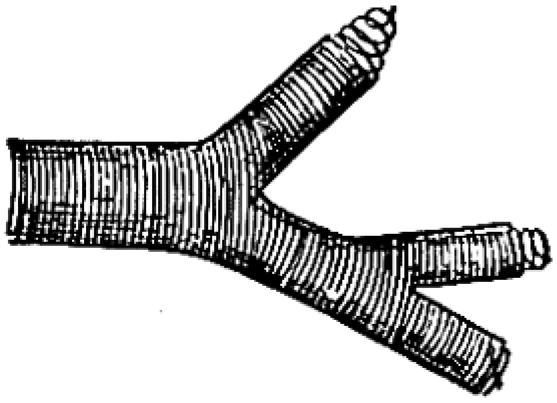
Fig. 126.—Tracheæ of the Caterpillar, Magnified.

In order that air may pass freely through the air-tubes it is necessary that the tubes should have rigid walls which do not collapse during the movements of the larva. By examining them under the microscope we can see how the necessary degree of rigidity is obtained, while at the same time the walls of the tubes are so thin as to allow the oxygen required for respiration to pass readily through them. Each tube is kept open by a spiral of a very slender but rigid and elastic filament, reminding one of the coiled wire that is sometimes employed to prevent the collapse of india-rubber gas-tubing.

We must now briefly describe the process of moulting, which should be observed by the student as opportunity occurs. After a few days of vigorous feeding the body of the caterpillar becomes too large for the surrounding skin, which does not grow proportionately, and has thus become tight and oppressive. At this stage the larva ceases to feed, and spins a carpet of silk to which it fixes itself firmly by means of its claspers and pro-legs. After a time it may be seen moving the front part of its body from side to side, until at last the tightened skin splits along the back of the first few segments, which protrude through the rent made. A series of convulsive movements may now be observed as the larva gradually releases itself from its old coat, which is eventually completely cast off, and left still attached by the hooks of the claspers to the silken carpet. The new skin now exposed is in every part soft and moist, but it soon reaches its normal condition as the moisture evaporates, while the portions that cover the head and the true legs gradually become hard and horny. The caterpillar then returns to its food with renewed appetite, and eats and grows with astonishing rapidity until, after a few more days, it has to undergo another moult. Thus the creature grows as it were by fits and starts, and casts its skin several times during its short life of about four weeks.

It is interesting to note that not only is the complete skin, including the horny coverings of the head and legs, cast off at each moult, but the lining of at least a part of the digestive tube is thrown off at the same time, as are also the linings of the tracheæ or larger air-tubes; and these internal membranes may be detected, attached to the outer skin, if the discarded garment be moistened with water, stretched out on a glass slip, and examined under the microscope.

THE PUPA.

When the larva is fully grown it leaves its food-plant and seeks a sheltered spot in a wall, paling, or other suitable position, usually some feet from the ground. Here it spins a carpet as before, to which it holds on securely by the hooklets of its claspers. It then bends the front segments of its body to one side, and applying its spinneret to the adjacent surface, carries a fine silk thread over to the opposite side, where it is again secured. This is repeated several times, the new silk being added while moist to the first thread, until at last the larva is supported by a very strong cord that holds it like a sling.

The larva has now to undergo its last moult. The skin splits along the back as before described, and the creature gradually pushes it towards the other end of its body until it is completely free, and the insect is now securely slung in the silken cord, while its "tail" holds fast to the silken carpet previously held by the claspers.

An examination of the creature will now show that important changes have taken place—changes which were in progress long before the final moulting. Its body is shorter, and of a very different shape. It is thickest a little to the front of the middle, tapers to a point both before and behind, and has several angular projections. The legs are apparently missing, and the claspers and pro-legs have gone. The head is no longer distinctly visible, the jaws have disappeared, and the creature has no mouth, its body being completely covered by a continuous skin. The hindmost portion of the body is distinctly segmented, and the only movements that may be observed are certain wrigglings of

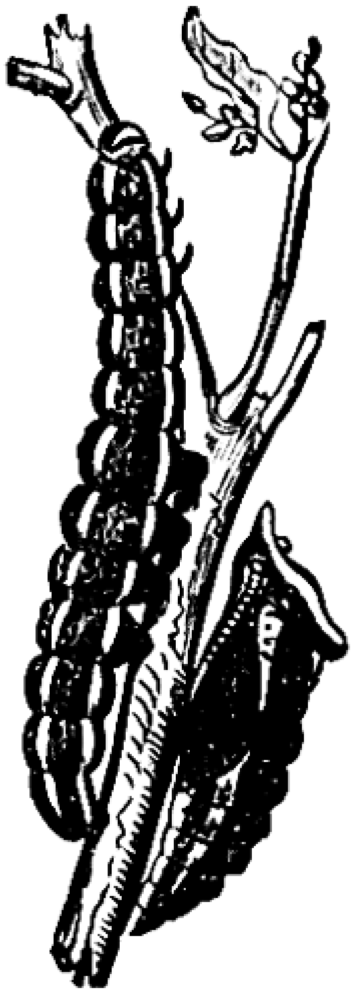

Fig. 127. — CATERPILLAR AND CHRYSALIS OF THE CABBAGE BUTTERFLY.

the body produced by the spasmodic bending of the segmented portion when the creature is irritated.

At first the skin is soft and moist, but it soon begins to dry and harden. It also assumes a blush-white colour, marked by several black spots and dots.

In this state the insect is known as the *chrysalis* or *pupa*. It takes no food of any kind, but remains in a perfectly passive condition for some time during which the parts of the future butterfly continue to develop. A careful examination of the chrysalis will reveal the positions of some of these parts. Thus, the places occupied by the large compound eyes are easily made out, and a projecting portion of the hardened skin below the head marks the position of the proboscis. The wing cases also, about half the length of the body, are easily outlined; and the positions of the legs can often be observed along the under surface.

We have already referred to the fact that the cabbage butterfly, in its perfect state, is most abundant during the months of April and July. The reason for this dual appearance is that there are two distinct broods of the insect during each year. The caterpillars that commit such ravages in our kitchen gardens during the autumn months change to the chrysalis state before the cold weather sets in, remain in the same condition throughout the winter, and the perfect insects emerge from them in late March or in April according to the temperature of the season. These form the "first brood," which deposit their eggs on our spring cabbages, thus giving rise to the caterpillars of May and June. The caterpillars of this brood are fully grown in June or early July, change to the chrysalis state forthwith, and, remaining in this state for a short period only, produce another brood of butterflies that appear on the wing during July and August.

Emergence of the Perfect Insect.

When the time has arrived for the final change the semi-transparent skin surrounding the chrysalis becomes loosened, and the colour and form of the insect within may be more distinctly seen than before. Movements may also be observed as the imprisoned insect struggles for liberty. As a result of these movements the loosened skin splits, the head, thorax and legs of the butterfly are immediately set free, and the creature at once walks out of the pupal skin and takes up a convenient position of rest while its wings expand and dry.

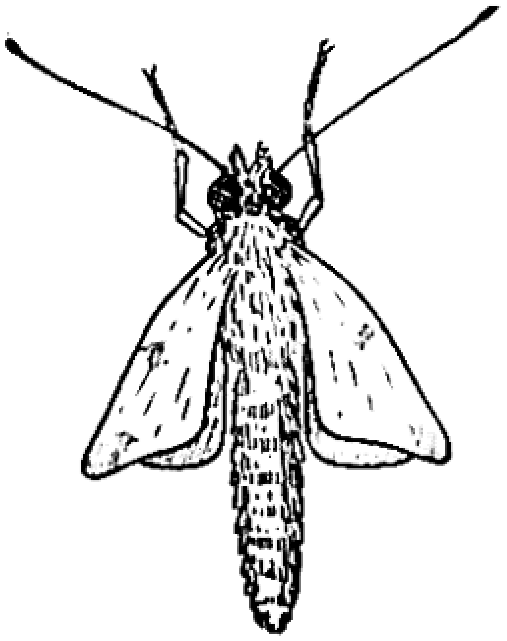
Fig. 128.—The Cabbage Butterfly as it emerges from the Chrysalis case.

When first the butterfly emerges its wings are moist and limp, and are not more than half the length of the body. They soon expand, however, and after a few minutes only they have reached their full size. But they are still very soft and limp, and the wing-rays are filled with fluid. Within an hour or so the fluid evaporates, leaving the wing-rays empty and the whole wing firm, rigid, and ready for use in flight.

All the above changes may be observed with ease by those who will take the trouble to rear the insect and watch it closely and frequently. It is true that the final change—the emergence of the perfect insect—occupies so little time that the chance of observing it may often be missed; but it should be remembered that the changes which may be observed through the semi-transparent chrysalis case will, after some experience, enable one to estimate the approximate time of the appearance of the butterfly. The condition of the weather at the time is also an important factor in the case; and if several chrysalides, judged to be ready for the final transformation, be placed in the direct rays of the sun in the morning (for the cabbage butterfly generally emerges early in the day), one may be almost sure of witnessing the change.

If we examine the wall or palings surrounding a kitchen garden we are certain to find clusters of little yellow silken cocoons, each about an eighth of an inch in length, generally beside the emaciated body or the shrivelled skin of a caterpillar of the cabbage butterfly. And if we rear the caterpillars that have been collected from cabbages in the open, we find that some of them never change to the chrysalis state, but may be found dead or dying just about the time that such change should take place, with a number of the little cocoons above mentioned by their side.

Preserve some of these cocoons in a glass bottle the mouth of which is stopped by muslin tied over it, and watch them from time to time. After a period, varying from a few weeks to several months, according to the time of the year, a number of very small four-winged flies will be found in the bottle.

These flies are called *Ichneumon Flies*, and they are great enemies to the cabbage butterfly. They deposit their eggs in or beneath the skin of the caterpillar, and the young *grubs* or *maggots* which issue from the eggs devour the fatty tissue that is formed in abundance just beneath the skin, and which is required for the growth of the organs of the future butterfly. Thus, as the caterpillar grows, the grubs within its body grow in the same proportion, so that it appears as plump and healthy as if it had not been attacked. When the caterpillar is fully grown the grubs have also reached their full size, and the

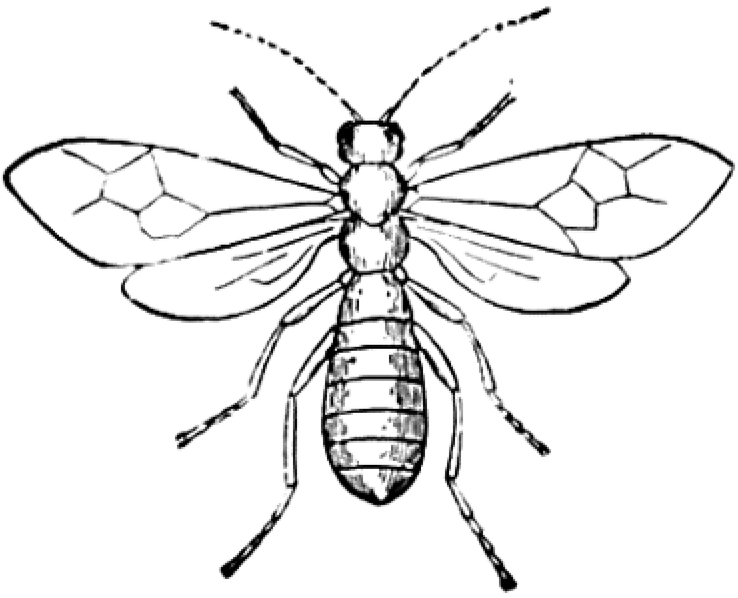

Fig. 129.—The Ichneumon Fly of the Cabbage Butterfly, Magnified.

latter then break through the skin and spin their silken cocoons outside, leaving the caterpillar in such an emaciated condition that it seldom changes to the chrysalis. The ichneumon grub changes to a pupa within its cocoon, and afterwards develops into the fly that we have just described.

THE GENERAL STRUCTURE AND CLASSIFICATION OF INSECTS.

Having now studied the structure and life-history of an insect we shall note the general characteristics of insects as a class, and then briefly deal with the principles of their classification.

The term insect signifies "cut into," and is applied to this group of animals because their bodies are usually divided into three distinct parts—head, thorax and abdomen. The head bears a pair of antennæ; and, generally, three pairs of mouth appendages. The thorax is made up of three ring-like segments, each of which bears a pair of legs, while, generally, the second and third of these segments each bears a pair of wings. The abdomen is composed of several segments, and bears no appendages of any kind.

Insects are also distinguished by their jointed legs, and by their hardened skin, which is rendered more or less firm by the formation of a horny substance called *chitin*. They breathe by a system of air-tubes (*tracheæ*), and often undergo *metamorphoses* or changes of form in the course of their growth. The nervous system consists of a chain of ganglia, joined together by a nerve cord, arranged centrally in the lower or ventral side of the body, and connected with a large ganglion or brain in the upper or dorsal part of the head.

Some of the above features are possessed by other animals, allied to the insects, but belonging to quite a distinct class; hence the definition of an insect would hardly be complete unless it included all the characteristics here given.

Insects are divided into several groups called *orders*, the classification being based principally on the nature of the wings (if present) and of the organs of the mouth. The student is strongly recommended to obtain as many as possible, and to compare them with the one described and with each other. The following table of classification is given as a guide for reference, to assist the student in this portion of his work. It gives a list of the chief orders, commencing with the most lowly organised:—

Order 1. *Rhynchota.* (Bugs, water scorpions, lice, etc.)
Mouth parts adapted for piercing and suction. Undergo no metamorphoses or only slight changes in form. Two pairs of wings or none.

Order 2. *Dermaptera* or *Euplexoptera.* (Earwigs.)
Mouth adapted for biting. Fore wings small; hind wings large but folded both longitudinally and transversely. A pair of forceps at the extremity of the abdomen.

Order 3. *Orthoptera.* (Cockroach, locust, grasshopper, cricket.)
Mouth adapted for biting. Fore wings parchment-like; hind wings larger and folded like a fan beneath the fore pair when at rest. (Wings sometimes absent.) No metamorphoses.

Order 4. *Odonata.* (Dragon flies.)
Mouth adapted for biting. Two pairs of large, unfolded, gauzy wings. Larvæ aquatic. Metamorphoses incomplete.

Order 5. *Neuroptera.* (Scorpion flies and snake flies.)
Mouth adapted for biting. Four glassy wings with many nervures or wing rays. Wings never folded.

Order 6. *Trichoptera.* (Caddis flies.)
Mouth adapted for biting. Hind wings usually larger than the fore pair and folded like a fan. Larvæ usually aquatic, and live in cases which they construct.

Order 7. *Aphaniptera.* (Fleas.)
Mouth adapted for both piercing and suction. No wings. No compound eyes. Body laterally compressed. Larva a footless maggot.

Order 8. *Diptera.* (House fly, gad fly, gnat, harlequin fly, etc.)
Mouth adapted for suction, and sometimes for biting. One pair of wings and a pair of "balancers." Larva generally a footless and headless maggot.

Order 9. *Lepidoptera.* (Butterflies and moths.)
Mouth adapted for suction. Two pairs of wings, covered (generally) with minute scales. Larva a caterpillar.

Order 10. *Coleoptera.* (Beetles.)
Mouth adapted for biting. Fore wings modified into hard wing covers. Hind wings folded when not in use Larvæ generally with six legs.

Order 11. *Hymenoptera.* (Ants, bees, wasps, gall flies, saw flies, etc.)
Mouth adapted for suction or biting or both. Four transparent wings. Larvæ generally footless grubs.

QUESTIONS.

1. Give a brief description of the life-history of any insect you have reared.

2. Give a brief description of the general form and structure of a caterpillar. How does it feed, and how does it breathe?

3. What are the principal characters which distinguish insects as a class?

4. It is intended that a class shall observe the growth and metamorphoses of an insect. Describe briefly the arrangements you would make and the methods you would adopt in order that the necessary observations may be made in the schoolroom.

CHAPTER X.

THE FROG.

(*Rana temporaria.*)

THE EGG.

DURING the first or second week of March, or a little later if the weather is severe, frogs may be seen in abundance in ponds and ditches almost everywhere. Here they congregate for the purpose of depositing their eggs, and before the end of the month one may see the clusters of eggs resting on the mud in shallow water, or supported by pond-weeds, to which they adhere, where the water is deeper. The frogs themselves at this season are seen resting or floating at the surface of the water, with their nostrils and prominent eyes just exposed; and their incessant croaking is to be heard, especially towards evening, as they call their mates after the winter hibernation.

The eggs laid by each female number some hundreds, and are all joined together by means of the transparent jelly-like covering that surrounds each black embryo or yolk. At first the gelatinous envelope is thin, and the egg, including this, is not more than about a sixteenth of an inch in diameter, but the envelope soon absorbs much water and swells enormously, till the eggs are a quarter of an inch or more in diameter, and the cluster of eggs assumes a size many times larger than that of the frog which deposited them.

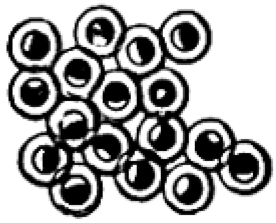

Fig. 130.—FROGS' EGGS AS THEY APPEAR WHEN JUST DEPOSITED.

A cluster of the eggs should be removed from the pond or ditch and transferred to a large shallow vessel containing a few inches of water. The vessel may be kept indoors for convenient observation, in which case it should be placed close to a window, but in such a position that it is not too much exposed to the direct rays of the sun. The water need never be changed, but a quantity of aquatic vegetation should be introduced. Nor will it be necessary to put any soil in the vessel, for the aquatic plants will thrive almost as well without it. The use of the vegetation will be obvious to those who have read the earlier portion of this book, for there it has been shown that green plants absorb carbonic acid gas under the influence of light, and give off oxygen. Thus, when the young of the frog have issued from the egg, they will be supplied with the oxygen necessary for respiration, while the carbonic acid gas liberated from their bodies as a product of respiration will be rapidly absorbed by the plants, and thus prevented from accumulating in the water.

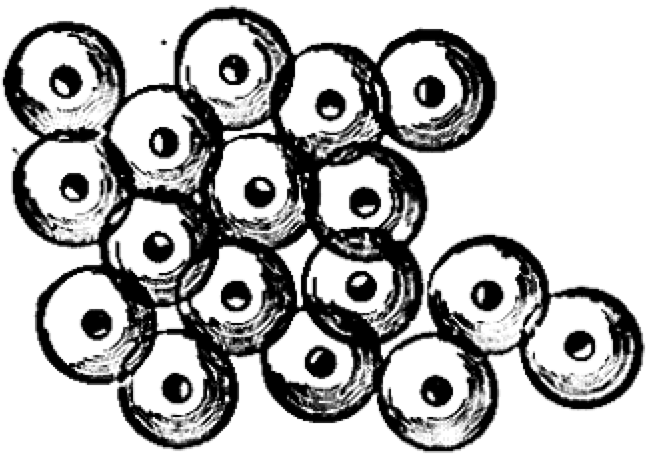

Fig. 131.—Frogs' Eggs a few hours after being laid.

Some plants are much better oxygen-producers than others, and among the common aquatic species we may mention particularly the American Pondweed (*Elodea* or *Anacharis*), the Hornwort (*Ceratophyllum*) and the Water Starwort (*Callitriche*) as very suitable for our purpose.

Having thus arranged the temporary aquarium, the eggs should be watched day by day, and every change in appearance entered in a note-book together with the date of observation. A series of sketches recording all such changes must also be made in proper order, and all observations and sketches may then be compared with those given in the following account of the life-history of the frog.

After a few days, varying considerably according to the temperature, the embryo changes from a spherical to an elliptical form, and shortly after it assumes a shape somewhat resembling a dumb-bell. A day or two later it becomes more fish-like in appearance, with a distinct tail, and is curled up in the gelatinous covering. Presently occasional movements may be observed, and shortly after the young *larvæ* or *tadpoles* will issue from the spherical masses of jelly and adhere to the surface.

The time occupied by the above changes is very variable, and depends on the temperature. In the open air about a fortnight generally elapses between the laying and the hatching of the eggs, but the time may be reduced to about half this in the case of eggs reared in a warm room.

TADPOLES.

At first the tadpoles are very inactive, and cling to the surface of the gelatinous mass by means of a pair of suckers on the under side of the head. At this stage, too, they have no mouths and are unable to take any food, but are nourished by the remains of the yolk ("food yolk") within their bodies. They exhibit a well-marked division into body and tail, and a magnifying lens will reveal a pair of developing gills, one on each side of the head.

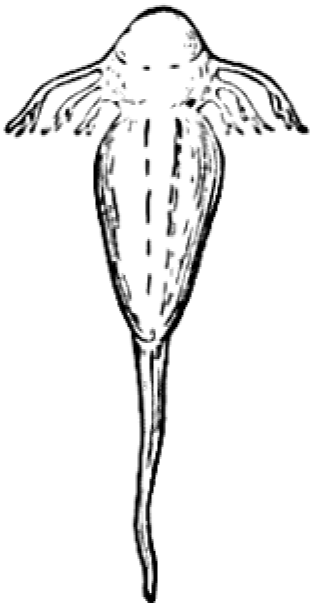

Fig. 132.—TADPOLE WITH EXTERNAL GILLS. FIVE TIMES NATURAL SIZE.

In a day or two after hatching they become very active, swimming about rapidly by horizontal undulatory movements of their tails, which are now longer, flattened laterally, and fringed with a transparent membrane above and below. The body is also more globular in form, and the gills have developed into feathery organs which are now very prominent. The mouth is now formed, and is provided with jaws of a horny nature by means of which the tadpoles can rasp the soft vegetable matter that forms their food. They now begin to move away from the gelatinous mass that formerly enclosed them, and attach themselves to pond weeds or to the surface of the vessel in which they are placed, and exhibit for a time a decided gregarious tendency.

At this stage not only does the tadpole grow rapidly, but the internal organs are also rapidly developing. The digestive tube, which was originally short and wide, is soon transformed into a long coiled tube. The heart and blood-vessels develop into a highly-organised system for the circulation of the blood, and the course of this fluid, as it passes through the small vessels (capillaries) of the tail-fringe, may be observed by placing a live tadpole in a drop of water under the microscope. The respiratory organs at present take the form of external feathery gills, though it is probable that a considerable proportion of the oxygen required is enabled to pass into the blood system through the soft skin that surrounds the whole of the body.

The nature and function of gills need some explanation. Gills are organs by means of which the oxygen dissolved in water can be absorbed and passed into the blood, and thus they differ materially from lungs, which extract the same gas direct from the air. A gill is richly supplied with blood, which flows through thin-walled vessels close to the surface of the organ. The organ itself is also surrounded by an exceedingly thin membrane through which gases can readily pass. Thus, as the gill is bathed by water in which atmospheric oxygen has been dissolved, this gas can easily pass through the thin structures which separate the water from the blood, while the carbonic acid gas that accumulates in the blood can as easily find its way from the blood to the water. Gases do not so readily permeate dry membranes, and thus we can understand why a gill-breathing animal, removed from its habitat, does not as a rule live long, even though its gills may be freely surrounded by atmospheric air.

Before the tadpole is much older important changes take place in the respiratory apparatus. The external gills gradually become smaller, and four little slit-like holes (*gill clefts*) are formed on each side of the body, immediately behind the head. The edges of these slits gradually turn inwards, and become internal gills, which are contained in a cavity that is in free communication with the mouth. The external gills now become completely absorbed, and a fold of the skin behind the head on each side grows backward, covers the gill clefts, and thus closes in the cavity in which the internal gills are situated. These folds of skin are termed *gill covers* or *opercula.* The posterior[1] edge of the one on the right side becomes continuous with the skin of the body, thus completely shutting in the gills on that side; but the left operculum only partially closes, leaving a hole which is distinctly visible on that side.

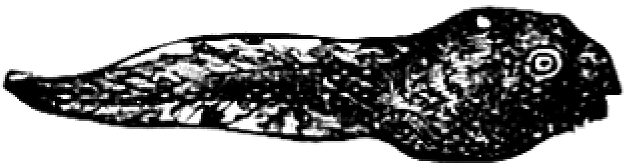

Fig. 133.—Tadpole with internal gills.

At this period the breathing is conducted as follows. Water is taken in at the mouth, and passes direct into the gill chamber on each side. After bathing the gills, and allowing the necessary exchange of gases to take place, it passes out again through the aperture of the left side.

As the tadpole grows larger it will be observed that the suckers have quite disappeared, but it still applies its head to the vegetable matter on which it feeds, and may be seen vigorously scraping away its food by means of the horny jaws at the under side of the head.

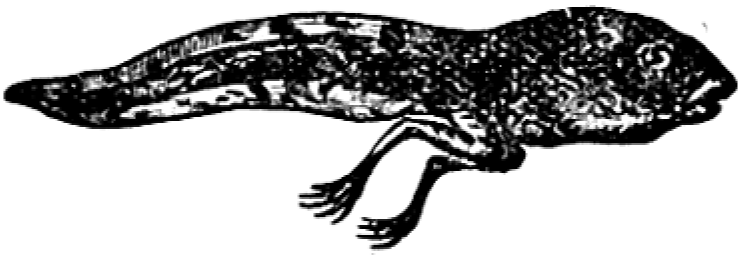

Fig. 134.—Tadpole with one pair of limbs.

The method of feeding may be observed most easily if we fill a large bottle with water, and leave it in a position where it will receive the maximum of bright sunshine. The surface of the glass will soon become coated with vegetation in the form of a bright green deposit; and if a few tadpoles be now introduced they may be watched through the glass as they rasp away the vegetable food.

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[1] Throughout this book the term anterior signifies "towards the head"; posterior, "from the head"; dorsal, "upper or back"; ventral, "lower or front"; and "right" and "left" always refer to the respective sides of the animal, and not of the observer.

After several weeks the tadpole has almost reached its maximum size, and now its legs begin to appear. A pair of projections become visible at the base of the tail, and these develop rapidly, becoming more and more like the legs of the frog. The fore limbs are developing at the same time, but do not protrude so early. They may, however, be seen folded beneath the gill covers, with the toes turned inwards on the under side of the body. The eyes also become more prominent, thus assuming a feature that obtains in the case of the adult frog.

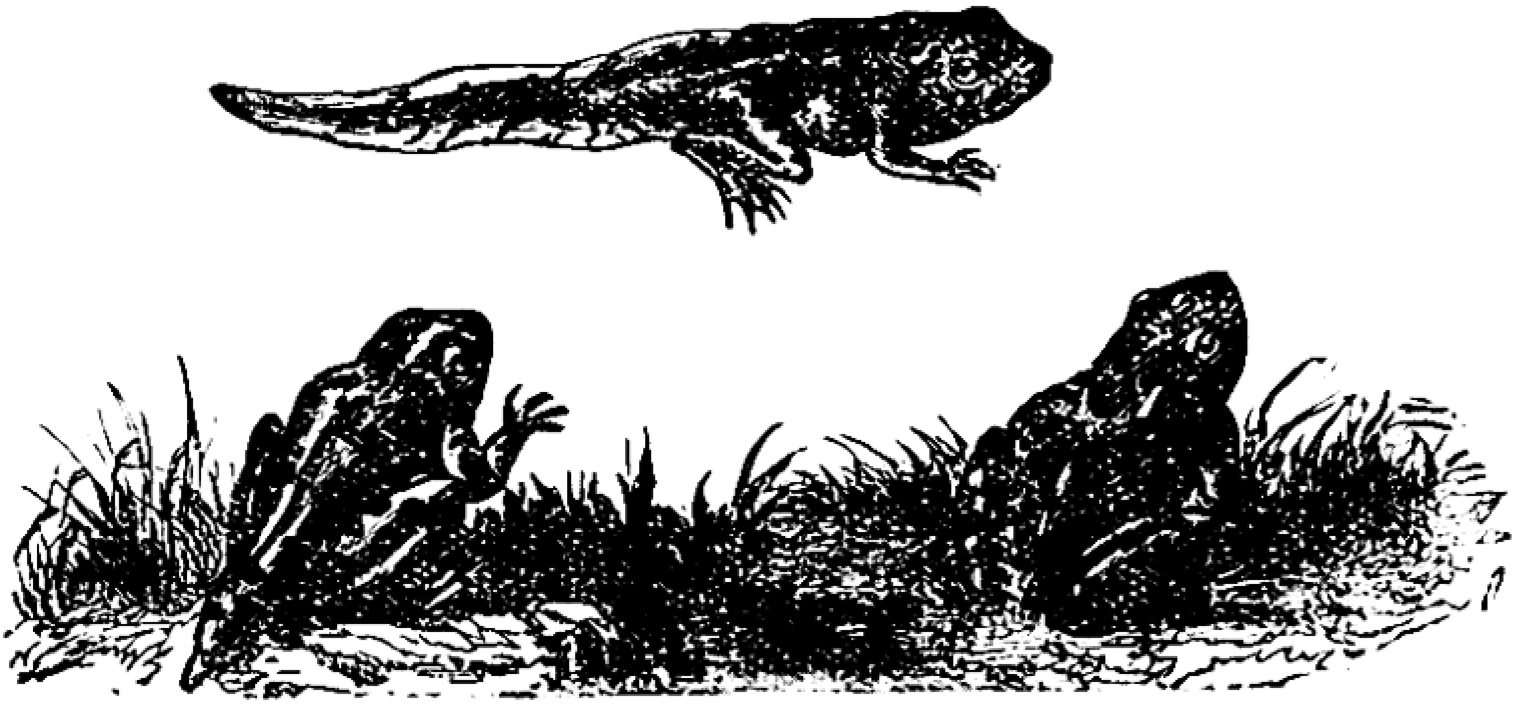

Fig. 135.—Young Frogs.

While these changes are progressing another remarkable alteration takes place in the breathing organs. The internal gills gradually lose their function, and finally disappear, while, at the same time, a pair of lungs are being formed. Thus for a time the tadpole breathes partly by means of its developing lungs and partly by the disappearing gills, and may be seen occasionally rising to the surface for a mouthful of air. Finally the function of the gills is entirely lost, and the oxygen necessary for respiration is obtained from the atmosphere direct. Even at this stage the young frog can remain submerged for long intervals, partly on account of the fact that the soft skin serves, as previously mentioned, the purpose of an accessory breathing organ.

As the tadpole is undergoing these metamorphoses, it also changes its food. At first it is purely a vegetable feeder, but after a time it begins to take animal food, and may be observed to feed on dead or decomposing animal matter, including the dead of its own species. Eventually it becomes purely carnivorous, living on small worms, the larvæ of aquatic insects, and insects in the perfect state.

It usually leaves the water when its limbs are well developed, and feeds on insects that it finds among the grass and other vegetation in the neighbourhood of the water; and at this time the tail gradually disappears by absorption, while the hind legs, becoming long and muscular, with webbed toes, enable the young frog to leap when on land as well as to swim when it returns to the water.

Frogs that are reared from the tadpole state in captivity should always be provided with floating weeds or a piece of sheet cork on which they may rest out of the water as their lungs come into use; and when the metamorphoses are completed it is advisable, as a rule, to set them free on account of the difficulty that is generally experienced in supplying them with the abundance of small insects and worms which they require. If it is intended to retain them in captivity they should be removed from the water and placed in an empty aquarium with a layer of moist turf at the bottom.

THE ADULT FROG.

We must now examine the adult frog in order to become acquainted with its external features and its habits; and for this purpose it will be advisable to place one in an empty aquarium, with turf, as above described, and to supply it with a variety of insects and small worms for food. A shallow vessel of water should also be included.

The body of the frog is of graceful form, and is covered with a soft, moist, smooth skin. There is no neck. The colour is very variable, but is usually yellowish, with dark patches. On each side of the head, behind the eye, there is a large triangular dark patch with its apex turned downward and backward. This is characteristic of the common English species, and has given rise to its specific name *temporaria*, the black patch being situated in the region of the temples.

When the frog is at rest there is generally a prominent ridge or hump across the middle of the back, which would seem to denote that the backbone is bent. This, however, is not the case, as we shall see when we come to examine the skeleton of the animal, but is due to the position of the hip bones.

The eyes are very prominent, thus giving a wide range of vision without any movement of the head. They are provided with lids, and can be withdrawn into their large sockets by muscular contraction, as may be observed when the eye is touched. The ear of the frog has no external appendage corresponding with that of the ears of quadrupeds, but the *tympanic membrane* or drum of the ear, which in ourselves is situated at the inner extremity of the canal of the ear, is at the surface of the head, continuous with the skin. It is the circular black membrane that may be seen just behind the eye, in the dark triangular patch above referred to. The mouth is very wide, extending practically from ear to ear, and above the mouth, in front, are two little holes which are the nostrils.

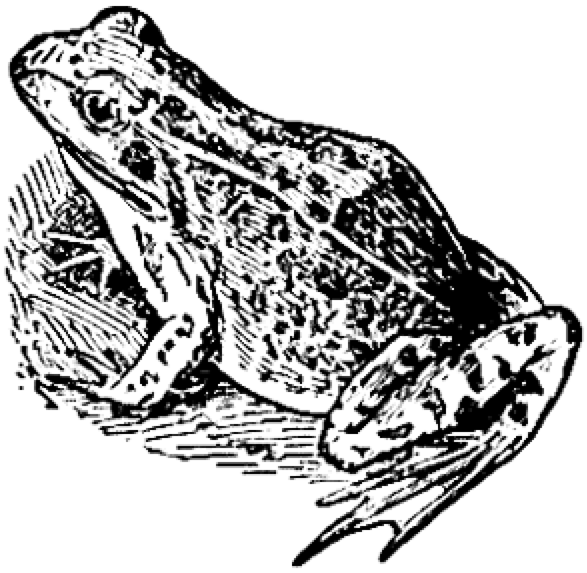

Fig. 136.—The Frog.

The fore legs are short, and the toes, four in number, are turned inwards and are not webbed for swimming. The hind legs are very long and muscular, and the five toes of the hind feet are also very long, and are connected by a thin web. It will be observed that the hind leg is doubled or folded into three long portions when the frog is at rest. The first of these is the thigh, and at its front end is the knee. The second portion is the leg, and the third, the longest of the three, is the foot, with the heel at its hindmost extremity. This will be better understood, however, when we study the skeleton.

The floor of the mouth of the frog is almost incessantly moving up and down, and if we watch the nostrils closely while these movements are in progress we find that they are sometimes closed by thin membranes that form a pair of valves. It will be seen also that the nostrils always close while the floor of the mouth is rising. These movements are connected with the work of respiration.

To understand this we must know that the lungs of a frog are not enclosed in an air-tight chamber completely shut off from the remainder of the general body cavity, as is the case with mammals, but that they occupy a portion of that cavity, in common with the other internal organs. They communicate with the cavity of the mouth by means of a slit-like opening (the *glottis*). The cavity can be enlarged or reduced in size by the contraction of two distinct sets of muscles. When air is inspired the nostrils are opened, and the cavity of the mouth enlarged. Air then rushes in to fill the increased space, being driven in by atmospheric pressure. The valvular nostrils are then closed and the size of the cavity reduced, thus driving the air from the mouth into the lungs. The lungs are in this way inflated; and, being highly elastic, they return to their former size and force the air back as soon as the muscles which reduced the cavity of the mouth relax. The respiratory movements of a mammal are of a very different nature, as may be seen by comparing the above with the brief account of the respiration of a mammal as given on p. 221.

The other movements of the frog should be studied by direct observation rather than from any written description. It will then be seen that the animal seldom walks, and when it does the movements are not very graceful, on account of the disproportionate lengths of the fore and hind limbs. The usual mode of progression is by a series of vigorous leaps caused by the sudden extension of the long hind legs. If a live frog is placed in a very large vessel of water, it will be noted that it also swims gracefully and rapidly with the hind limbs, aided by the extended web between the toes.

The method of feeding is very interesting, and no difficulty lies in the way of observing this, since a frog, kept in captivity for a short time, will take its food readily, even when closely watched. It may be fed on small earthworms, and insects of various kinds, including small beetles, moths, flies, caterpillars, etc. Certain species, however, are distasteful to the frog, and such species owe their safety, and consequent abundance, to the fact that they are disliked by frogs and other insectivorous creatures. Thus, a hungry frog may capture a caterpillar of the currant moth (*Abraxas grossulariata*), but the grub will be instantly released with evident signs of discomfort on the part of the frog.

A worm is usually captured by means of the jaws, and has but little chance of escape on account of the holding power of the teeth. These teeth are so small that they are hardly to be seen without the aid of a lens, but may be easily felt by passing the tip of the finger around the margin of the upper jaw and the roof of the mouth. They are sharp and curved backwards, and thus effectually prevent the live prey of the frog from slipping out of the mouth.

The more active insects and the smaller prey of the frog are always captured by means of the tongue. This organ is attached to the *front* part of the floor of the mouth, and is composed principally of muscular fibres by means of which it can be thrust out suddenly to some considerable distance. It is aimed at insects with wonderful precision; and the captured prey, adhering to the moist tongue, is instantly pulled into the mouth and swallowed alive, for the frog does not masticate its food.

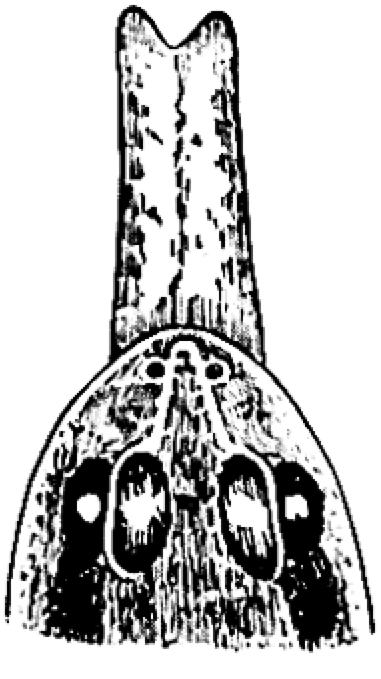

Fig. 137.—HEAD OF THE FROG, FROM ABOVE, SHOWING THE BILOBED TONGUE.

The skeleton of the frog forms a useful study, and we strongly recommend the reader to prepare his own specimen because much useful knowledge concerning the general internal structure of the animal will be gained as the process of dissection proceeds.

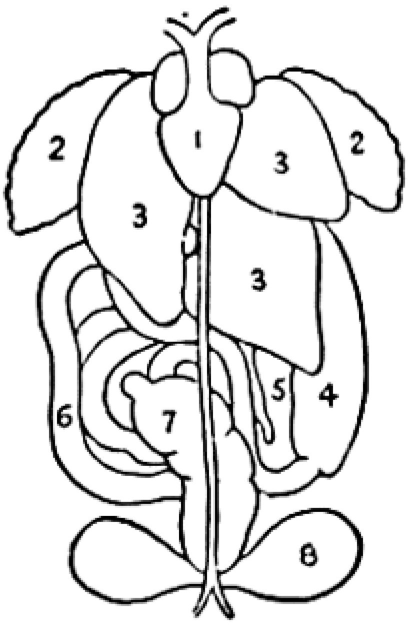

Fig. 138.—THE VISCERA OF THE FROG AS SEEN ON REMOVING THE BODY WALL.
(1) Heart, (2) Lungs, (3) Liver, (4) Stomach, (5) Pancreas, (6) Small Intestine, (7) Large Intestine, (8) Bladder.

To this end a recently killed frog should have its internal organs removed, and all soft parts carefully dissected away without injury either to the bones or to the ligaments that hold the bones together at the joints. The arrangement of the internal organs and the principal muscles should be carefully studied as the work proceeds; and the majority of the former may be readily identified by means of the accompanying illustration. The skeleton thus roughly cleared should be macerated in water for a few days, and cleaned at intervals by means of a small but moderately stiff brush. When properly cleared, it may be set aside in an airy place to dry.

The backbone or *vertebral column* consists of nine distinct rings or *vertebræ*, each of which consists of a thickened mass of bone (the *body*) on the ventral or lower side, and a bony arch enclosing a cavity above. Thus the whole forms a tube, which contains the nerve cord called the spinal cord or marrow. There are also small openings between the vertebræ through which pass several pairs of nerves that issue from the spinal cord. Various bony parts called *processes* project from the vertebræ. Some of these give attachment to the muscles of the back, while others serve to link the vertebræ together into a flexible column.

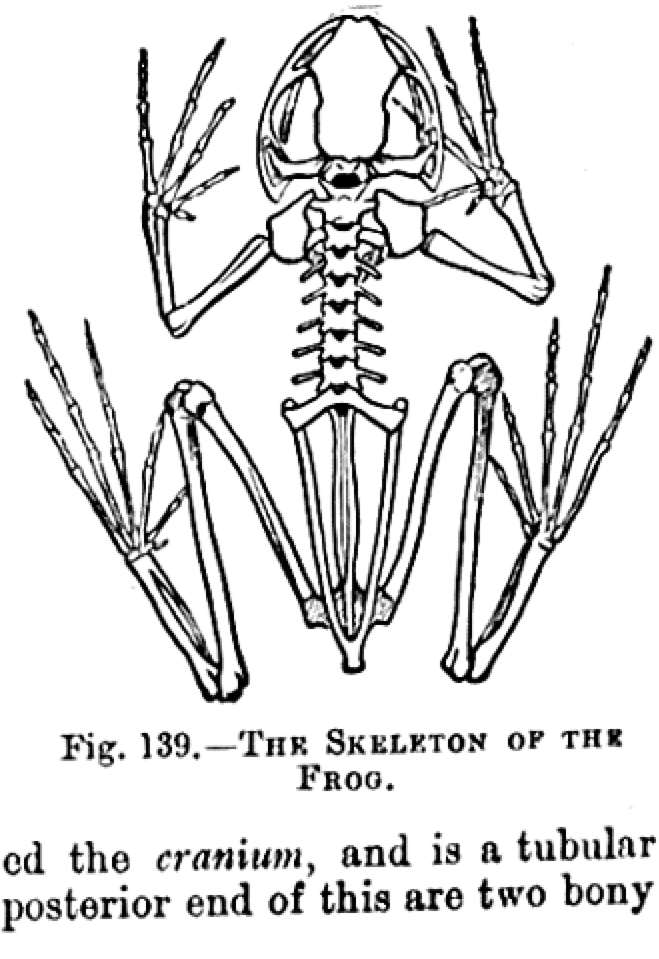

Fig. 139.—THE SKELETON OF THE FROG.

The first vertebra is jointed to the skull, and at the junction the spinal cord is continuous with the brain. The ninth has two stout processes that are attached to the long pelvic or hip bones, and it is at this junction that the back of the living frog often appears bent or humped Behind the ninth, and jointed to it, is a long bony rod (the *urostyle*) which extends to the posterior end of the hip.

The skull consists of a number of bones and membranes, most of which are immovably joined together. The middle portion is called the *cranium*, and is a tubular case, enclosing the brain. At the posterior end of this are two bony masses which fit into the first vertebra, and almost surround the opening in which the brain merges into the spinal cord. On each side of the posterior portion of the cranium there are also the capsules which contain the structures of the inner ear, while at the anterior end are the cavities that contain the organ of smell. At the sides may be seen the openings through which the nerves of vision (*optic nerves*) pass from the brain to the eye. The teeth of the upper jaw should be examined with a hand lens, as well as the two small clusters of teeth on the triangular bones (*vomers*) which form part of the roof of the mouth.

The two shoulder girdles together almost completely surround the front portion of the spinal column or backbone, and are attached to the skeleton of the trunk by soft structures only. Each girdle consists of a thin triangular shoulder-blade (*scapula*) that lies over the backbone, and a pair of bones (the slender *clavicle* or collar-bone and the stouter *caracoid*) which pass from the apex of the shoulder-blade to the middle line below, where they are joined together. Passing backwards and forwards from the junction is the breast-bone, both portions of which consist of a bony rod and a thin, flat plate of cartilage.

The upper and lower portions of the girdle unite at the side to form a hollow (*glenoid cavity*) into which fits the rounded head of the bone of the arm (*humerus*). The lower extremity of this bone forms a hinge-joint with the bone of the forearm, which is termed the *radio-ulna*, since it corresponds with the two bones—radius and ulna—that compose the forearm of higher animals. The radio-ulna is followed by six small carpal or wrist bones, arranged in two rows of three, and these again by four *metacarpal* bones, each of which supports a finger. The first and second fingers consist of two bones, and the third and fourth of three. An imperfectly developed thumb may also be observed attached to the inner side of the wrist.

The structure of the leg is very similar to that of the arm. The long thigh bone (*femur*) fits into a hollow (*acetabulum*) at the side of the posterior portion of the hip. The other end of the femur is jointed to a single bone (*tibio-fibula*), which represents the two parallel bones (*tibia* and *fibula*) of higher animals. The ankle or *tarsus* consists of two long bones which are united together at both ends, and two very small bones beyond these. Jointed to the ankle are five long *metatarsal* bones, each of which gives attachment to a toe. There are five well-developed toes, made up respectively of two, two, three, four and three bones, commencing with the inner, which corresponds with the great toe of man.

AMPHIBIANS.

The frog is a member of the class of animals known as the *Amphibians*. The group forms one of the main divisions of the *Vertebrates* or back-boned animals, which are characterised by the possession of an internal skeleton, the principal part of which is the vertebral column; hence the term *vertebrate*.

The *vertebrata* include Fishes, Amphibians, Reptiles, Birds and Mammals.

Amphibians (also called *Batrachians*) resemble fishes and reptiles in that they are cold-blooded, while the two other groups are warm-blooded. They may be distinguished from the other vertebrates by the following characteristics:—

1. They undergo changes or metamorphoses.
2. In their early stages they are more or less fish-like in structure and habit, and breathe by gills.
3. The gills are not as a rule permanent, as in fishes, but are replaced by air-sacs or lungs as the adult stage is reached.
4. Though fish-like in their earlier stages, they never possess fins with distinct fin-rays like those of fishes.
5. Ribs are either absent or are very short. (It will have been observed that the frog has no ribs.)
6. They have usually four limbs, very unlike the fins of fishes, but consisting of parts comparable with those of the higher vertebrates.

The British amphibians, which number only seven species, may be classified into two main groups:—

1. *Urodela* or *Caudata*, in which the tail is permanent.
2. *Anura* or *Ecaudata*, in which the tail disappears as the adult stage is reached.

The former division includes Newts and Salamanders, and the latter embraces Frogs and Toads. The following table of classification deals with the British species:—

Class **AMPHIBIA**.
  Order CAUDATA.
    Family **Salamandridæ**.
      1. The Great Warty Newt (*Molge cristata*).
      2. The Common Smooth Newt (*Molge vulgaris*).
      3. The Palmate Newt (*Molge palmata*).

  Order ECAUDATA.
    Family **Ranidæ**.
      4. The Common Frog (*Rana temporaria*).
      5. The Edible Frog (*Rana esculenta*).

    Family **Bufonidæ**.
      6. The Common Toad (*Bufo vulgaris*).
      7. The Natterjack Toad (*Bufo calamita*).

Of the above we have described the common frog, and the student is advised to obtain as many as possible of the others, keep them in captivity, and carefully observe their general form and habits, especially noting those points in which they resemble and differ from each other.

QUESTIONS.

1. Give a general description of the external characters of a frog. and show how it is adapted to its peculiar mode of life.
2. Describe briefly how a frog walks, leaps, swims, and breathes.
3. Give a brief description of the management of an aquarium in which the development and movements of tadpoles are to be observed.
4. Describe the development of the tadpole from the time that it leaves the egg.
5. What changes are to be observed with the naked eye in frogs' eggs from the time when they are laid?
6. Describe exactly how a tadpole breathes, and how it feeds

CHAPTER XL

THE BIRD:

ILLUSTRATED BY THE PIGEON (*Columba domestica*).

FEATHERS.

For the general study of the principal features of birds we can hardly do better than select a pigeon or dove, and the reader should make it a point to carefully study the form and habits of a tame specimen previous to a more detailed examination of the structure of its parts.

The most striking feature of birds in general is certainly the characteristic clothing of feathers, of which we shall first note the kinds, general arrangement, and structure.

Feathers are of two kinds. First, there are the larger *contour* feathers which determine the outline of the bird when in flight; and, second, the soft *down* feathers which are more particularly concerned in maintaining the warmth of the body.

A careful examination of the arrangement of the feathers made by raising them and noting their insertion in the skin will show that the larger ones are placed in definite tracts. The root of each one issues from a sheath formed by the skin dipping downwards obliquely, and sections of the skin reveal slips of muscle that are inserted in the roots in such a manner that, by their contraction, they pull the roots, and consequently the feathers, into a more erect position. The importance of these muscles becomes evident when we observe the various movements of the feathers as the bird is engaged in cleaning and adjusting its coat or preparing for flight.

All feathers are to be regarded as outgrowths of the epidermis or outer skin, for the microscopic examination of a longitudinal section of the roots shows that they are produced by the constant addition of new cells in the same manner as the epidermis itself, the additions being made at a "growing point" situated at the bottom of the sheath above mentioned.

The principal contour feathers are often classified into the rowing and the steering feathers; for while those of the wing are the means by which the bird propels itself in the air, those of the tail are employed in steering the bird in its course.

Let us now examine a contour feather obtained from any bird. We observe that it consists of a central axis with a hole at its lower extremity. The bottom portion of this axis is round and hollow, and is sometimes called the *barrel;* while the upper part (the *rachis*) is square and solid.

On each side of the latter are the flat portions of the feather, known as the *vanes.* Hold the feather by the barrel in one hand, and, with the other, gently pull a portion of a vane downwards. The part thus pulled brings down with it the higher portion of the vane, but eventually we succeed in breaking the continuity. If we now press the separated parts between the finger and thumb, rubbing them gently from axis to margin, we find that they readily unite again.

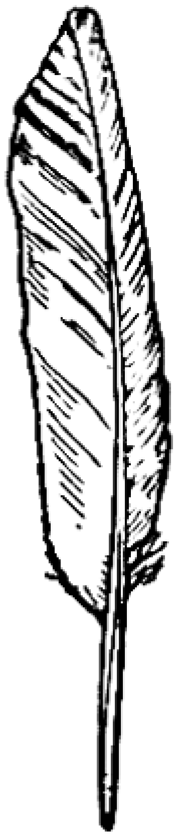

Fig. 140.—A Contour Feather.

The parts into which the vane is separable are called *barbs,* and each vane consists of hundreds of such barbs, passing obliquely upwards from the axis, arranged regularly and parallel, and all united into a continuous sheet. The importance of this continuity of the vane is evident when we consider that the bird has to use such feathers as a means of propelling itself through the air.

Remove a single barb and examine it under the low power of a compound microscope, or even with a good hand lens, the barb being placed on a surface of a colour that offers great contrast with that of the barb itself, *e.g.* a white barb on black paper. It will now be seen that smaller barbs (*barbules*) branch off from the main barb, and that these are furnished with hooklets of different shapes. The hooklets near the base of the barb are somewhat like minute knife-blades, but are bent near the middle, and have a few small teeth in the bend. The edges of the upper barbules are drawn out into delicate spines, some of which are only slightly curved, while others are distinctly hooked.

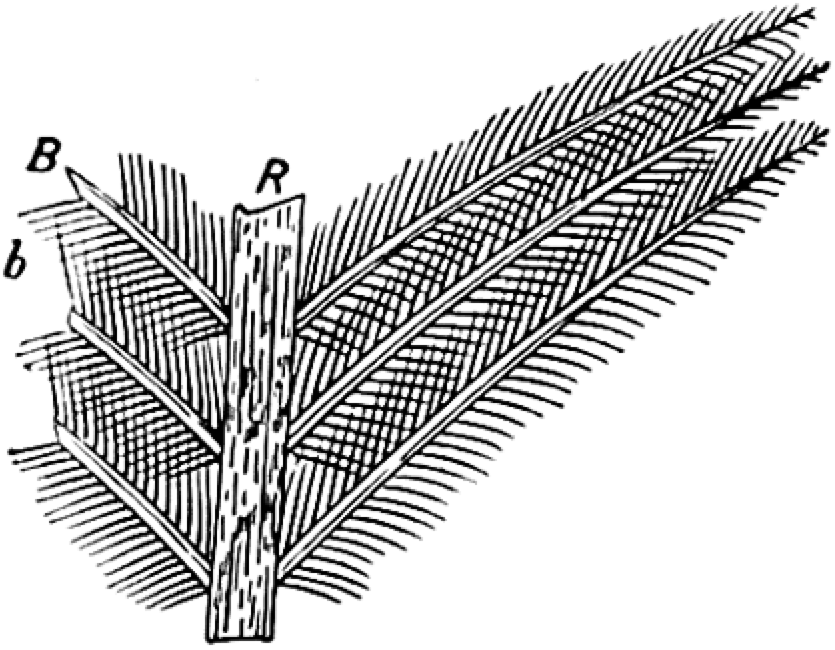

Fig. 141.—Portion of a Contour Feather.
(R) Rachis, (B) Barb, (b) Barbules.

We are now in a position to understand how it is that the barbs of a vane are so effectually bound together; and the more so when we examine a small portion of a feather with barbs and barbules *in situ*, and note that each barbule passes off obliquely from the barb in such a manner that it overlaps several barbules of the adjacent barb.

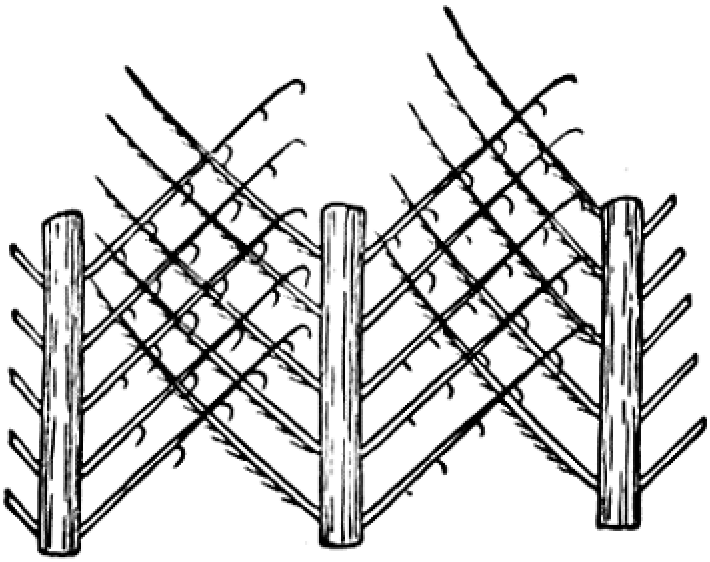

Fig. 142.—A small portion of a Contour Feather magnified, showing barbs and barbules *in situ*.

In the typical down feather (of which there are very few in the pigeon), such as one taken from the breast of a bird, we find that the barbs are not continuous, but loosely and freely arranged. The principal function of such is to keep the bird warm by preventing the escape of heat from the body. It is a well-known fact that feathers are very poor conductors of heat, and their value to the bird is greatly enhanced by the looseness of the texture formed by the mass of down, for an amount of air is necessarily lodged between the overlapping and interlacing barbs, and air is even a worse conductor of heat than the feathers themselves.

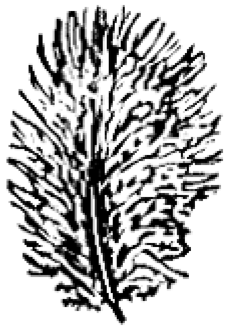
Fig. 143.—A Down Feather.

It is interesting to note in this connection that birds are the hottest of all animals, the blood temperature being generally several degrees higher than that of mammals. Further, in birds that do not fly, as the ostrich, all the feathers partake of the nature of down feathers; and such is also the case with all nestlings.

If we raise and extend the wing of a bird, examining it from below, we observe that there are no down feathers in the tracts occupied by the contours.

The feathers of a bird are not permanent structures, for, as is well known, birds "moult" at regular periods, new feathers being formed as the old ones are shed.

To protect the feathers from the influence of moisture there is a gland at the root of the tail that secretes an oily fluid. This fluid lubricates the feathers, and thus prevents them from being easily wetted.

The colours of birds are most varied, and, especially in the case of tropical species, often of dazzling brilliancy The colour is partly due to pigment, and partly to structure. If white light be allowed to fall on a bright surface that has been closely ruled with exceedingly fine lines, the light waves are deflected in such a manner as to give rise to colour bands corresponding with the tints of the rainbow; and some of the brilliant hues of birds are produced in a similar manner by the finely striated structure of the feathers. It is interesting to note that none of the British birds are of a pure white colour, and in only a few species does this colour predominate.

OTHER EXTERNAL CHARACTERS.

The legs of birds are generally covered with scales, but in some species these limbs are feathered. The scales are hardened plates of the outer skin (*epidermis*), and such scales are formed only on the bodies of birds and reptiles. The scales of fishes are of a totally different nature, being formed not by the epidermis, but by the true skin or *dermis.* In the case of the pigeon the upper part of the leg is feathered, while the lower portion is covered with hexagonal scales.

The pigeon's feet have four toes, all covered with scales, and terminating in a curved toe-nail or claw. Three of the toes are directed forward, and one backward.

Remarkable variations are to be met with in the feet of different birds, the form and structure in each case being adapted to the habits. Thus the perching birds generally have slender toes, arranged like those of the pigeon—three directed forward and one backward; while the climbers, such as the woodpecker, have two directed forward and two backward. All the truly aquatic birds have their toes more or less completely webbed for swimming; and carnivorous birds are provided with strong toes and sharp curved claws that enable them to seize their prey.

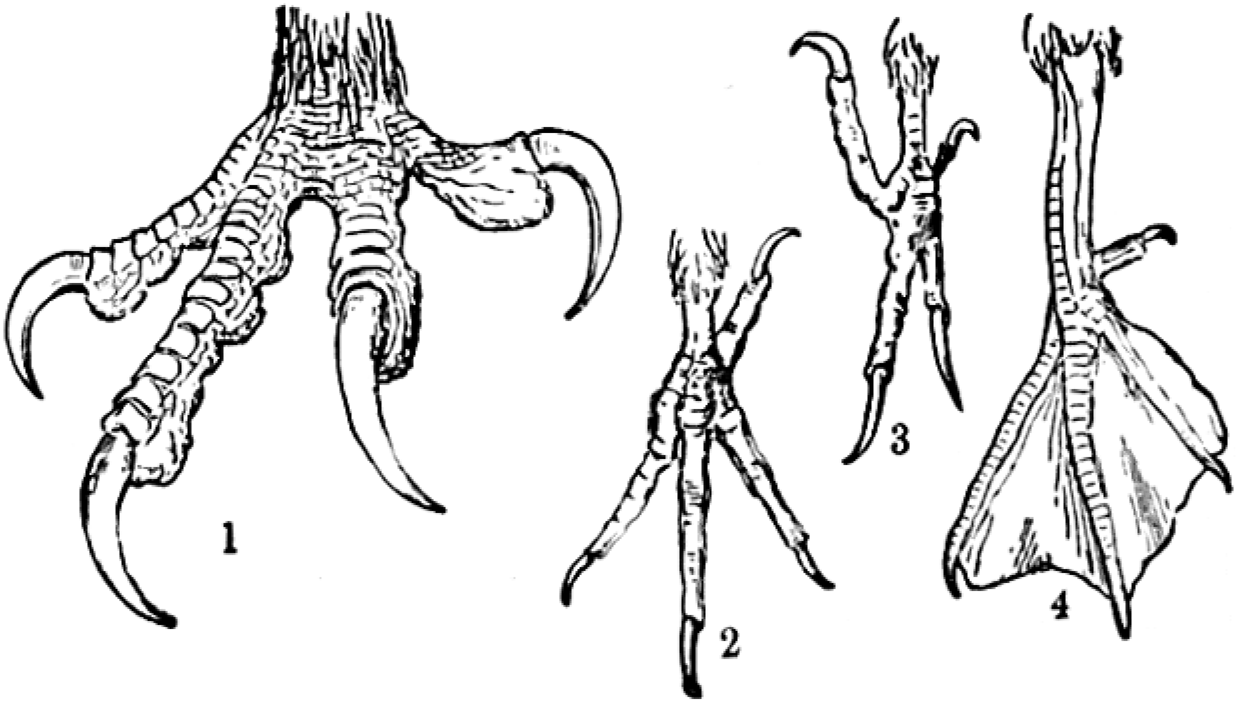

Fig. 144.—THE FEET OF BIRDS.
1, EAGLE; 2, PIGEON; 3, WOODPECKER; 4, DUCK.

Birds have no teeth with which to masticate their food, but all are provided with a prehensile beak, ensheathed in horny skin, to seize and hold their food. The form of the beak exhibits as great a variety as the feet. That of the pigeon is swollen towards the tip, and has a mass of soft sensitive tissue at the base, below which the nostrils are situated.

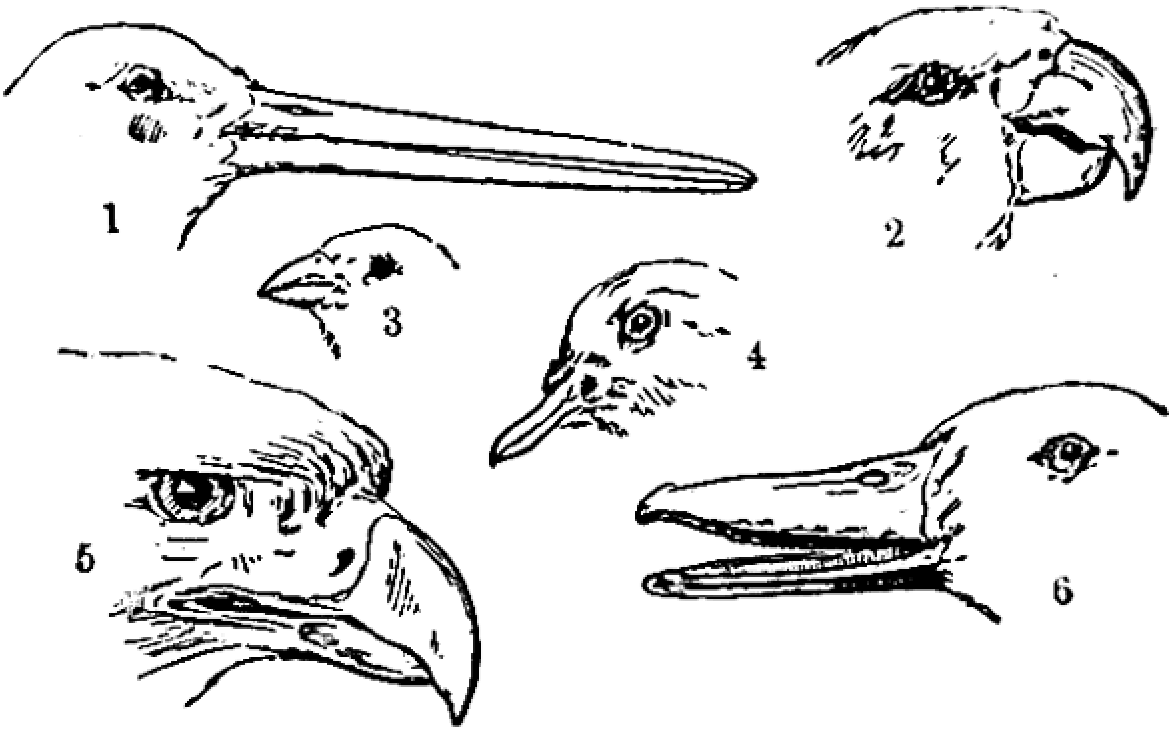

Fig. 145.—The Beaks of Birds.
1, Stork; 2, Parrot; 3, Sparrow; 4, Pigeon; 5, Eagle; 6, Duck.

The majority of beaks are conical in shape, but they vary considerably in length in accordance with the habits of the species. In birds of prey, such as the hawk and the owl, the beak is curved and sharp, and serves as a means of tearing the flesh of the prey. Another interesting form is the shovel-shaped bill of the duck, that serves admirably for dabbling in the mud from which the food is obtained.

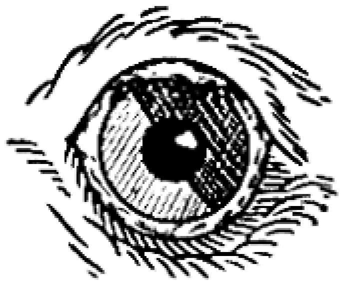

Fig. 146.—Eye of a Bird, showing the Third Eyelid.

The eye of the bird also should be examined closely. It is remarkable for the possession of a third eyelid or *nictitating membrane* in addition to the usual upper and lower lids. This third lid is situated below and within the ordinary lids, and is pulled upward by the contraction of two muscles on the back of the eyeball.

There is also an additional gland that pours out a watery secretion to keep this lid moist and render its movements easy.

The tongue of birds is not usually so useful as the corresponding organ in many other vertebrate animals. In some it is quite absent, and in many others it is a mere horny projection. There are, however, some important exceptions to this rule. Thus the tongue of the parrot is soft and fleshy, and assists the bird in the manipulation of its food. That of the woodpecker is very long and protrusible, and barbed at the tip, and is of great service in enabling the bird to extract the insects on which it feeds from the deep crevices of the bark of trees. Some small tropical birds have tubular tongues adapted for suction, while others possess tongues with frayed-out edges that enable them to collect the nectar from flowers.

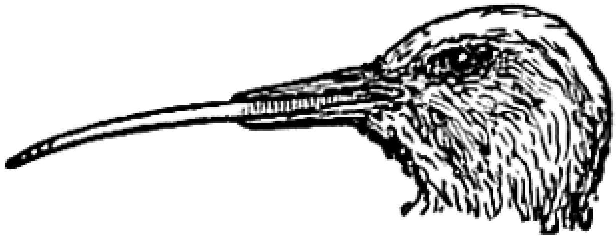

Fig. 147.—Tongue of the Woodpecker

The Skeleton.

Having now noticed briefly the external features of the bird, we must give some little attention to the peculiarities of the skeleton.

It is probable that, in many instances, the reader will be unable to obtain a prepared skeleton for study, and will thus find it necessary to prepare his own specimen. This may be done in the same manner as is briefly outlined in the case of the frog; and during the process an opportunity will be given for the study of the general arrangement of the internal organs and the principal muscles.

The peculiar form of the digestive tube should be particularly noted, especially the glandular *crop* in the neck, in which food is stored and moistened before it is passed into the stomach. Note also the very thick and muscular *gizzard*, in which the food is masticated with the aid of grains of sand which have been swallowed for the purpose. The general nature of the digestive tube is shown in the accompanying illustration.

In connection with the breathing system of the bird a very important characteristic must necessarily be mentioned. The body of the bird must be rendered as light as possible to adapt it for free movement in the air; and to this end we find numerous air spaces in various parts of the body. Some of the divisions of the trachea pass through the bottom of the lungs, and lead into large air-sacs which surround their lower surfaces. These air-sacs permeate the whole body—between the internal organs, among the muscles, beneath the skin, and even into the interior of the hollow bones, which contain membranous air-canals instead of marrow. Many of these air-cavities may be readily traced by the careful dissection of a bird, aided by the blowing of air down the trachea, or even into a broken bone. It will be interesting, too, to break some fresh bones of a bird and a mammal (*e.g.* the rabbit), to note the differences in the thickness of the material of the bones and the contents of their cavities. The above remarks do not apply to the heavy birds, like the ostrich, which do not fly. Young birds in the nest, too, have, at first, marrow in their bones, but this is afterwards absorbed in some, and air takes its place.

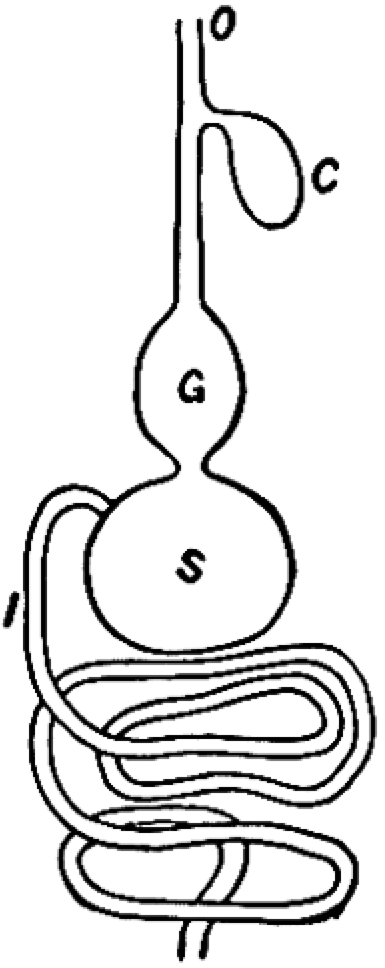

Fig. 148.—The Digestive Tube of a Bird.

O, Œsophagus; O, Crop; G, Gizzard; S. Stomach; I, Intestine.

The heart of the bird may be examined and dissected, but its structure and function will be dealt with more conveniently in our chapter on physiology, where the circulation of blood in the mammal, the bird, and the frog will be compared.

The skull is smooth and rounded. The brain-case (*cranium*) at the back is proportionately much larger than that of the frog. On removing the skull by cutting through the ligaments that unite it to the first vertebra, we observe the large opening at the back, where the brain becomes continuous with the spinal cord, and also note that the skull has only one bony mass that fits into the first vertebra, whereas, in the case of the frog, we observed two. It will be clear that this arrangement gives much greater freedom of movement. The true nature of the beak may be ascertained by stripping the horny sheath from the bones beneath.

The vertebral column of the pigeon consists of a number of vertebræ, some of which have grown into a solid mass, while others form moveable joints. The neck consists of fourteen bones, each of which forms moveable joints with the adjacent ones. Most of them bear short spine-like ribs, but the last two have longer ribs. The number of vertebræ forming the neck of birds varies in different species, but is never less than nine, and may be

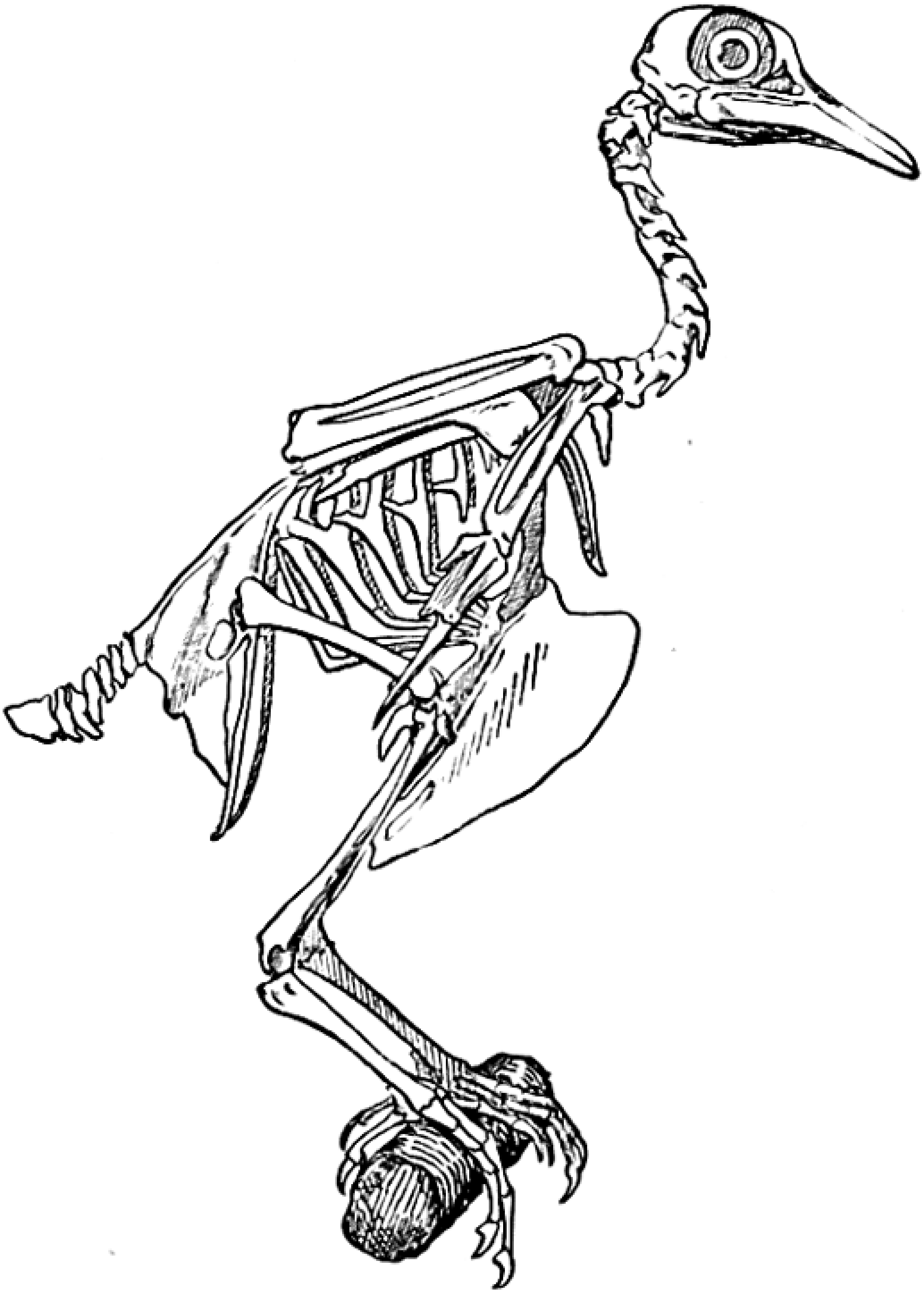

Fig. 149.—Skeleton of the Pigeon.

as high as twenty-three. The number of neck vertebræ in mammals is always seven, and the larger number in the bird will account for the extreme mobility of the head, which is still further increased by the manner in which the head itself is mounted on the first vertebra; for, as we have already observed, a single bony eminence (*condyle*) at the back of the skull fits into a depression in the first vertebra, thus forming a joint that permits of a rotatory movement. The length of the neck and beak of a bird is usually proportionate to that of the leg.

The next five vertebræ, forming the front portion of the back, each bear a pair of ribs that are connected with the breast-bone, and the ribs themselves are joined together near the top by bony spurs. It will be noticed, too, that the five vertebræ in question have all grown together.

The hindmost vertebræ of the back have also grown into a rigid mass, forming what is called the *sacrum*; and to each side of this is attached the large pelvic or hip bone, the whole constituting a bony arch that covers the posterior portion of the body-cavity.

Behind the sacrum are the bones of the tail, the first six of which are movable on each other, while the remainder have grown into a flat "ploughshare" bone that forms a base on which the tail feathers rest. The whole backbone encloses a canal in which the spinal cord is lodged.

The *sternum* is a very large bone, the chief characteristic of which is the enormous "keel" that provides the increased surface necessary for the attachment of the powerful muscles of the wings. The under portions of the ribs are attached to the sternum, and these are jointed to the upper portions that pass down from the vertebræ of the front part of the trunk. This arrangement allows the up and down movements of the sternum for the purposes of respiration.

We must now examine the limbs of the bird, and it will be very instructive to compare them, as we proceed, with the corresponding limbs of the frog.

The fore limbs or wings are attached to the trunk by means of the shoulder girdle, which consists of three pairs of bones. The first of these is a stout pair of bones (*caracoids*) passing from the top of the breast-bone to the shoulder joint; the second is a pair of slender collar bones (*clavicles*) that extend downwards from the shoulder joint, and then unite to form the V-shaped bone popularly known as the "merrythought"; the third pair are the *scapulæ* or blade bones, which are joined to the caracoids at the shoulder, and then pass backwards in the form of scythe-like blades over the ribs, being held in their places by muscles.

The bone of the upper wing or arm (the *humerus*) is very strong. Its large upper head forms a ball-and-socket joint at the junction of the shoulder bones, while the other end hinges with the bones of the fore-arm. The latter consists of two bones—the thinner *radius* and the thicker *ulna*—joined together by ligaments at their ends, but the former is not capable of a rotatory movement round the latter as in the case of our own fore-arm.

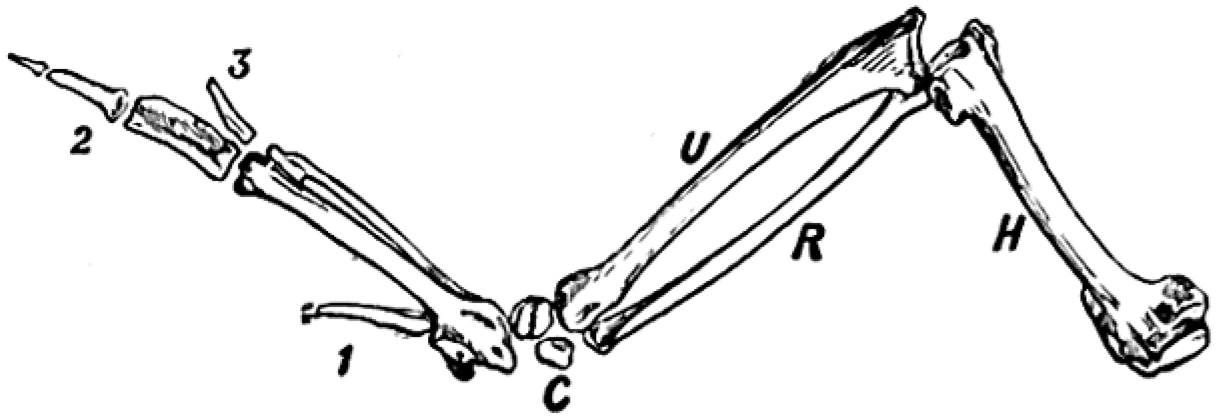

Fig. 150.—The Wing of a Bird.
H, Humerus; R, Radius; U, Ulna; C, Carpus; 1, 2, 3, Fingers.

The hand, which is more or less consolidated, is hinged with the lower head of the ulna. There are two small movable carpal or wrist bones, and two large metacarpal or hand bones grown together at their ends. A one-jointed thumb (Fig. 150, 1) is attached to the wrist, and supports a distinct tuft of small feathers. At the lower end of the metacarpus are two fingers, one large one made up of two segments, and a second of one segment.

The student should carefully examine the wing of a bird in which the bones have been laid bare, and in which the principal feathers have been allowed to remain undisturbed. Such a wing should be straightened out in order to show the main feather tract along the ulna, the outer side of the metacarpus (the side opposite the thumb), and the corresponding side of the largest finger. The manner in which the feathers are supported by the flattened portion of the finger, and the tuft of feathers belonging to the thumb should also be observed. The wing should then be folded into the position of rest and the arrangement of parts again studied.

Turning our attention now to the legs (Fig. 149), we find that the thigh bone (*femur*) forms a ball-and-socket joint with the pelvis bone, its rounded upper head fitting into the cup-like *acetabulum*. The lower end of the femur hinges with the leg, forming the knee joint which is situated close against the lower ribs. The leg is made up of two bones, the very large *tibia* or shin bone, and the small *fibula* or splint bone which grows into it on the outer side. The lower end of the tibia joins the consolidated ankle and instep bones (*tarsus* and *metatarsus* respectively), forming the heel joint some distance above the ground. There are four well-formed toes, each terminating in a curved claw. The first toe is turned backwards, and is made up of two

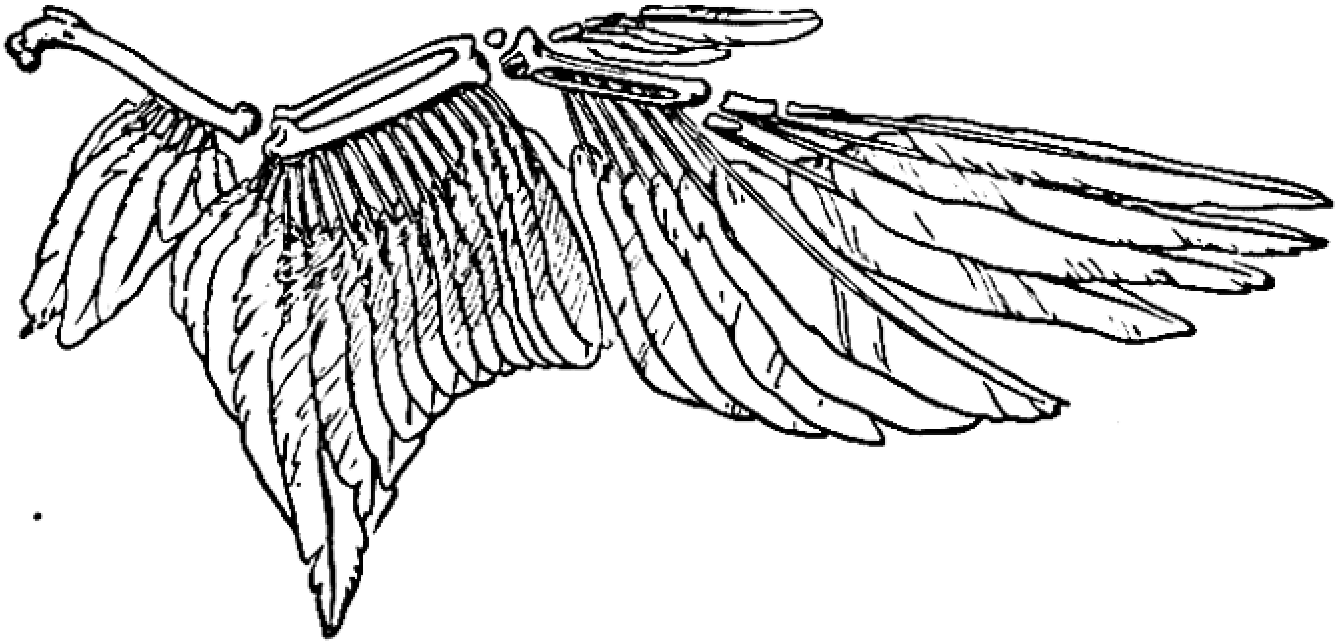

Fig. 151.—The Wing of the Pigeon, showing the Bones and the principal Feathers.

bones. The other three are directed forwards; and of these the outer has four bones, the middle one three bones, and the inner two (Fig. 144, 2).

Finally, in revising the structure of the bird's skeleton the greatest attention should be paid to its adaptation to habits. The principal points bearing on this adaptation have already been referred to. Another is to be found in the growing together of so many of the bones of the back, thus giving a degree of rigidity that enables the framework to stand the enormous strain produced by the powerful organs of flight. Other similar features will suggest themselves to the intelligent student. We also repeat the suggestion that the bones of the bird and of the frog should be placed side by side in order that their parts may be compared; and where considerable variations occur the student should himself endeavour to grasp their significance in the light of his knowledge of the habits of the living animals.

Having now observed the principal characteristics of a bird we must note the fact that birds as a class are so remarkably uniform in character that it is a very easy matter to give a definition which readily distinguishes them from all other animals. Thus while birds and mammals (milk-giving animals) are the only warm-blooded animals, the former are always characterised by their clothing of feathers, while the latter never possess feathers. But the remarkable uniformity of structure just referred to has made the classification of birds themselves a very difficult matter. This difficulty, however, will hardly concern us, for in the following simple outline of classification we shall deal only with a few of the more evident features such as would appeal to an ordinary observer, and these only so far as they apply to well-known species. Further, in order to simplify the classification we shall avoid some technical terms and expressions which would be of no service to the reader. As opportunity offers, the student should closely observe the general external structure and habits of different kinds of birds, carefully noting resemblances and differences.

OUTLINE CLASSIFICATION OF BIRDS.

Division I.—Birds with no keel to the sternum.—Running birds.

Order 1.—Ostriches, etc.

Division II.—Birds with a keel to the sternum.

Order 2.—Sea-birds in which the legs are placed so far behind that the birds stand with bodies erect. Examples—Puffins and Guillemots.

Order 3.—Sea-birds in which all four toes are included in a stout web. Example—Pelicans.

Order 4.—Swimming birds with webbed feet and flattened bills.—Ducks and Geese.

Order 5.—Swimming birds with webbed feet and long, pointed wings.—Gulls and Terns.

Order 6.—Wading birds with long legs and bills, and long hind toes.—Storks.

Order 7.—Wading birds with long legs and bills, and short hind toes.—Plovers, Coots and Herons.

Order 8.—Scraping birds with stout claws and plump bodies, that scrape in the ground for their food.—Fowl, Turkey, Partridge, Pheasant, etc.

Order 9.—Vegetable-feeding birds with a large crop that sometimes secretes a milky fluid.—Pigeons and Doves.

Order 10.—Birds of prey with strong curved claws and hooked bills.—Eagles, Owls and Hawks.

Order 11.—Perching birds with slender toes.—Song birds generally.

Order 12.—Climbing birds with two toes directed backwards, and long protrusible tongues.—Woodpeckers.

Order 13.—Climbing birds with two toes directed backwards, hooked beaks, and soft fleshy tongues.—Parrots.

QUESTIONS.

1. Show in what respects the bird is particularly adapted to an aerial life.

2. Point out the principal differences between a contour feather and a down feather. Explain the advantages of these differences to the bird.

3. Describe the feet and beaks of any three birds you have observed, and show how they are structurally adapted to the bird's mode of life.

4. Give a brief description of the structure of the wing of a bird, mentioning particularly the arrangement and attachment of the feathers. How are the wings moved?

5. What is the use of the keel of the breast-bone of a bird?

6. Mention the more important points of difference between the skeleton of a bird and that of a mammal.

CHAPTER XII.

MAMMALS:

ILLUSTRATED BY THE RABBIT AND A FEW OTHER TYPES.

THE mammals or milk-giving animals form the highest division of the animal kingdom. This division includes mankind, monkeys, the aerial bats, the so-called quadrupeds, and the aquatic seals, whales and porpoises, all of which suckle their helpless young. Our knowledge of these animals will be obtained by the observation of a few common domestic and other easily obtained species, our attention being given principally to

THE RABBIT.

Procure a live tame rabbit for the purpose of studying its external features and movements. Note first the general form and covering of the body. The latter consists of a very dense coat of fine, silky hair, commonly known as fur, and consisting of some longer hairs and a very thick, shorter "under-hair." The clothing of hairs is characteristic of the mammals, though in the whales and some thick-skinned species it is not permanent. In some, as the hedgehog, the hairs are spine-like, while in others they are united into scales such as we see on the tail of the rat.

As regards the general form of the rabbit, we observe a very distinct division into head, neck and trunk. The neck gives great freedom of movement to the head, admitting an easy command of the surroundings without the necessity of changing the position of the body. We have previously observed that the frog has no neck, and the same condition obtains in the aquatic mammals, the bodies of which are more or less like that of the typical fish, and therefore well adapted for easy progress through water.

Passing the hand over the back of the rabbit we note the strongly curved form of the backbone, which dips down at the neck, arches over the back, and is then continued as a chain of very small bones through the upturned tail. The ribs may also be felt at the sides of the narrow thorax or chest, uniting with the breast-bone on the ventral side; and the absence of bony framework may be noted at the sides and ventral portion of the large, plump abdomen.

The tail of the rabbit is very characteristic. It is very short, and turned sharply upward, exposing the pure white fur of the ventral side. Thus, though short, the tail is rendered very conspicuous, and is supposed to serve as a directive signal to the young when they are feeding in the open.

The two pairs of legs are of very unequal lengths, the front ones being very much shorter than the others. As a result the rabbit is unable to walk after the manner of most other quadrupeds, but progresses in a series of leaps made by the extension of the long and muscular hind limbs. The fore feet have five distinct hairy toes, each terminating in a blunt claw, and the fore limbs are well adapted to the burrowing habits of the animal. The hind limbs have four similar toes. It should be observed, too, that the rabbit rests with the soles of its feet flat on the ground. This is particularly noticeable in the long hind feet, the heels of which touch the ground.

Turning our attention now to the head of the rabbit, we note the very long appendages of the ears, thin and soft at the tip, where they are folded longitudinally, and cartilaginous (gristly) at the base. These appendages are held erect, except in the case of the pendulous ears of the "lop-eared" varieties of tame rabbits—a product of artificial selection—and are of a form well adapted for the collection of sound waves. They are also freely moved by muscles, and are instinctively directed by the animals towards the direction from which the sound proceeds, though this is not so noticeable in tame ones, to whom, of course, such movements are not so essential.

The eyes are comparatively large and prominent, and are closed by upper and lower lids that bear a few eye-lashes. The nictitating membrane, which we have already observed as a third well-developed eye-lid in the pigeon, is here a soft white fold of moist skin in the inner corner of the eye, and serves to clean the front of the eyeball as the latter rotates within its bony socket.

On each side of the snout we see a few long bristly hairs, and these, being attached to a highly sensitive portion of the skin, are undoubtedly valuable as organs of touch, especially to the rabbit in its burrow.

The nostrils, at the end of the snout, are two slits, connected with the mouth by a vertical cleft in the upper lip. This same feature obtains in the hare, and hence the common term "hare-lip" often applied to the similar lips of other creatures.

The method of using the teeth should be observed in the live rabbit, especially as it nibbles or gnaws away at a moderately large piece of carrot or cabbage-stump. The action of the chisel-like front teeth is thus made clear, and the nature of the teeth themselves may be observed by parting the soft lips.

Another important feature of the mouth, more conveniently observed in a dead specimen, should receive some attention. Behind the incisor or cutting teeth in the front of both jaws there is a wide gap, and beyond this are molar teeth adapted for the mastication or grinding of the food. At each gap the skin of the lips is hairy within, and projects inward between the two sets of teeth, meeting in the middle, and thus dividing the cavity of the mouth into two parts. This arrangement evidently serves as a kind of strainer, preventing any objectionable matter from entering the throat.

The rabbit belongs to the *Rodents* or gnawing mammals, easily distinguished from all others by the nature and arrangement of their teeth and their mode of feeding. The other British rodents include the hares, squirrels, beavers, rats, and mice; and tame specimens of any of these should be observed as opportunities occur. The well-known domestic guinea-pig, introduced from South America, is also a rodent.

The general form of a vertebrate animal is, of course, to a great extent determined by the nature of the skeleton, which should thus receive a little attention even when a knowledge of the internal anatomy is not directly desired. Should the reader desire to prepare the skeleton of a rabbit for study, he may proceed as previously directed in the case of the frog (p. 158).

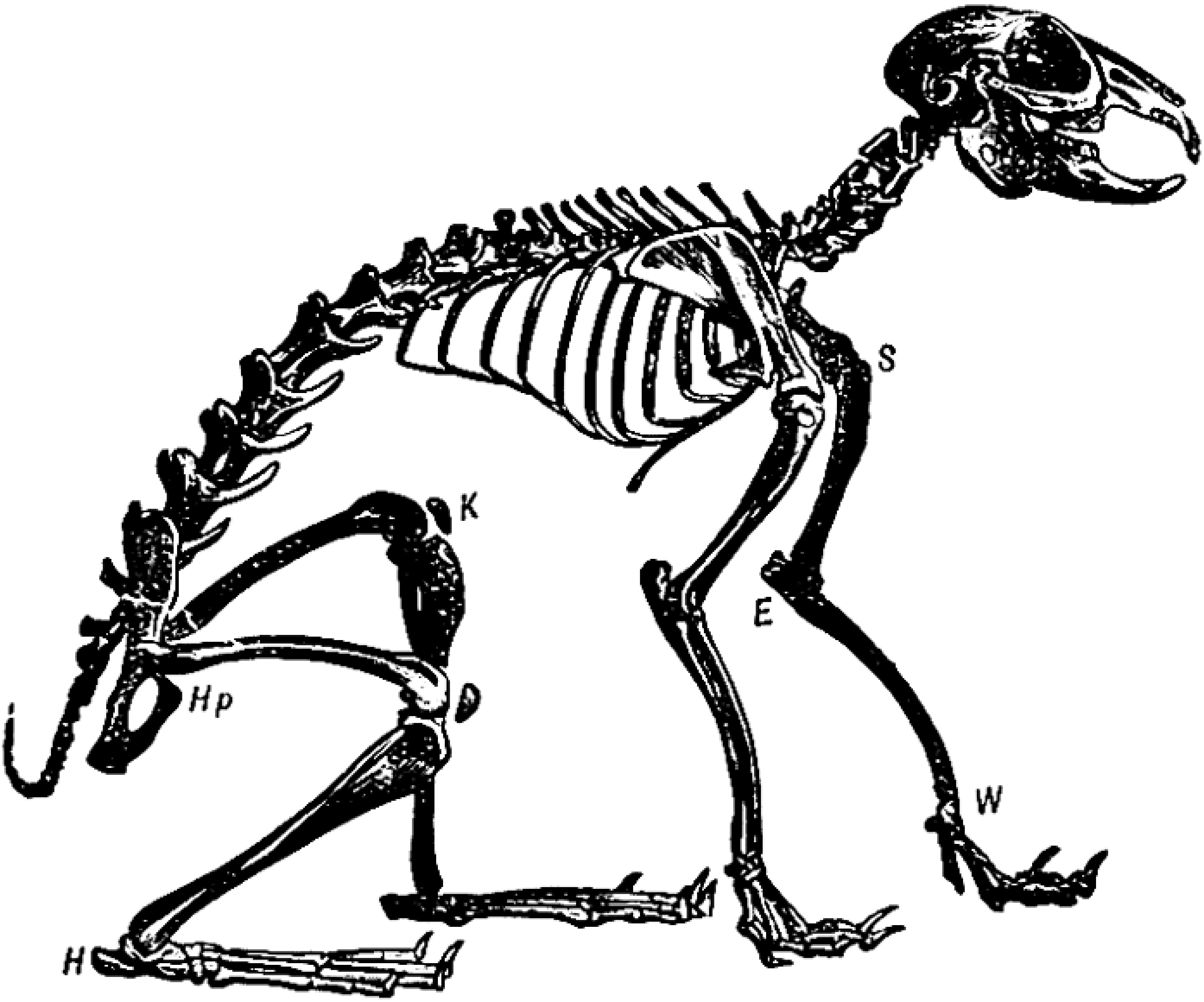

Fig. 152.—SKELETON OF THE RABBIT.

S, shoulder-joint; *E*, elbow; *W*, wrist; *Hp*, hip-joint; *K*, knee; *H*, heel.

After taking a general view of the skeleton as a whole, the skull should be examined, and compared with those of the frog and the bird. Note especially the *two* condyles that fit into corresponding depressions in the first vertebra (called the *atlas*), and observe that the arrangement allows the skull to *rock* vertically on the spinal column, and not to *rotate* as in the pigeon. Note also that the cranium or brain-case consists of several bones jointed together at their edges by irregular seam-like joints; that the cavities of the nose are rendered very complicated by numerous bony plates; and that the lower jaw is jointed to the skull in such a manner that it can slide a little backwards and forwards to facilitate the mastication of the food. Further, observe the arch of the cheek, the form of the eye-sockets, the hole through which the optic nerve enters from the brain, and the bulb-like bones at the sides of the skull that contain parts of the organs of hearing.

The nature of the teeth may now be more closely observed than in the living animal, particular attention being paid to the very sharp incisors. Of these there is a pair in the front of each jaw, and a pair of much smaller ones may be seen *behind* those of the upper jaw. The crown of a tooth—that portion which projects above the gum—is usually covered with *enamel*, a very hard substance composed almost entirely of mineral matter, while the remainder consists principally of a softer substance called dentine or ivory. In the rodents, however, the enamel is either absent or thinner on the posterior surface; thus, as these teeth are brought into contact during the habitual gnawing of the animal, the posterior part wears away faster than the front, so that the front edge of the teeth is always kept bevelled and very sharp. These teeth

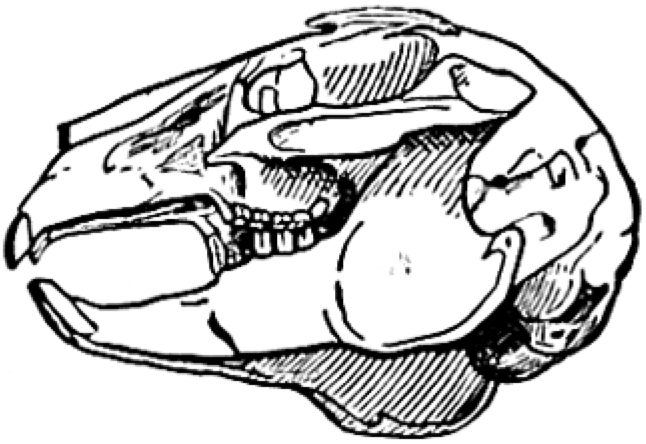

Fig. 153.—Skull of the Rabbit.

also penetrate far into the jaw, as may be seen by removing one; and they grow in proportion as they wear away. There are six molars or chewing-teeth on each side of the upper jaw, and five on each side of the lower jaw.

The vertebral column of the rabbit is a long chain of bones forming a tube through which the spinal cord runs. Seven of these bones form the neck. Then follow several thoracic or chest vertebræ, each bearing a pair of ribs, and larger ones forming the loins. All the above are distinct bones, united together by discs of cartilage, but behind the loins are some vertebræ grown into a solid mass (the *sacrum*), at the posterior end of which are the distinct vertebræ of the tail.

The vertebræ are all built on one plan, and a typical one removed from the thoracic region should be examined. It consists of a mass of bone (the body) from which two arches extend upwards. The arches unite in the middle line, enclosing the *spinal cavity*, and are then extended to form the *spinous process* that serves for the attachment of the muscles of the back. Other *lateral processes* serve the same purpose; and in addition there are a pair of processes that help to support the heads of the ribs, and still another pair that overlap the succeeding vertebra and serve, with the aid of ligaments, to bind the two bones together.

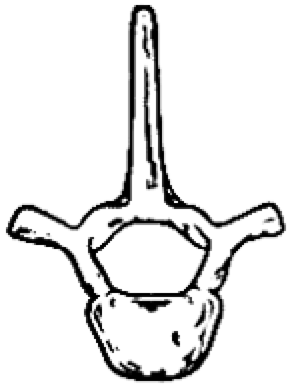

Fig. 155.—A Typical Vertebra of the Rabbit.

The first vertebra (the *atlas*) is a ring of bone, without a body, having, as previously noted, a pair of depressions to receive the condyles of the skull. The body of the second (the *axis*) sends a process forward into the cavity of the first, and this process is held against the atlas in such a manner that the atlas is capable of a rotatory movement on the axis. Thus, while the skull can simply rock vertically on the former, it can rotate on the latter, carrying the atlas with it. Other differences in the various vertebræ should be noted, especially their relative sizes, thicknesses of the "bodies," and the modifications of their processes.

Note that there are twelve or thirteen pairs of *ribs* attached to the thoracic vertebræ. The first seven of these are attached by cartilages to the sternum. The eighth and ninth are similarly attached to the ribs above, and the others are free or "floating ribs." The sternum itself is a narrow jointed plate, the first and largest segment being keeled to give better attachment to muscles which move the fore limbs, and the last segment is cartilaginous.

The *shoulder girdle* consists of a shoulder-blade (*scapula*) and a collar bone (*clavicle*). The former is a triangular bone with a prominent ridge or spine, and a shallow depression to receive the head of the humerus. It represents both the scapula and the coracoid of the frog and the pigeon. The latter is imperfectly developed, being a slender bone, only about an inch in length in the full-grown rabbit, and does not reach the sternum. This bone, however, is usually strongly developed in mammals that grasp, climb, or burrow with their fore limbs, and in them the whole girdle is generally somewhat massive.

The rounded head of the *humerus* forms a ball-and-socket joint with the scapula, and its lower extremity hinges with the fore-arm. The latter consists of two distinct bones, the *radius* and the *ulna,* but the former is not capable of a rotatory movement round the latter as in our own arm. The ulna sends a process backwards round the lower head of the humerus. This (the *olecranon process*) limits the motion of the fore-arm and strengthens the joint.

Attached to the lower extremity of the forearm are nine little *carpal* or *wrist bones,* arranged in two rows with a central bone between the rows. Beyond these are five *metacarpal* or *hand bones,* each of which supports a finger or *digit.* Each digit is made up of three bones with the exception of the thumb, which has only two.

Having noted the general structure and the fore limb as above, place the limb of the rabbit side by side with those of the frog and the pigeon and compare them, carefully pointing out the corresponding parts in each.

Passing now to the hind limb, we first note that the *pelvis* or hip consists of two large bones between which the sacrum is firmly wedged; the bones also meet and are connected together in the middle line below. Each hip has a cup-like cavity (*acetabulum*) into which fits the head of the *femur* or thigh-bone, forming a ball-and-socket joint.

The leg consists of two bones, the larger *tibia* and the smaller *fibula*. The latter, which is on the outer side of the leg, is very slender, and grows into the former below. There are two rows of *tarsal* or *ankle bones*, with a central bone between the two rows on the inner side. One of these is a moderately large one, extending backwards and forming the heel. Then there are four long *metatarsal* or *instep bones*, each supporting a digit of four bones.

Now compare the arm with the leg of the rabbit—the shoulder girdle with the pelvic girdle, the upper arm with the thigh, the fore-arm with the leg, the carpus with the tarsus, the metacarpus with the metatarsus, and the fingers with the toes. Also compare the corresponding parts of the legs of the rabbit, the pigeon and the frog. Such comparisons are particularly instructive, and the student will do well to obtain separate limbs of the above animals and of other easily-obtained mammals, mount them all on a card, and initial all the parts for future study.

If we observe a live rabbit in its standing attitude, comparing it with the diagram of the skeleton on page 179, we note that the animal rests with its heels and the whole sole of the hind foot on the ground, also that nearly the whole of the fore foot, from the wrist to the claws is placed on the ground. This characteristic obtains in most rodents, and all the mammals that stand supported in this way are spoken of as *plantigrade* animals.

THE SHEEP AND OTHER DOMESTIC RUMINANTS.

Observe a live sheep, and note generally the form of the head, with its fleshy lips, large nostrils, large eyeballs, ear appendages, and horns if present. Note also the distinct neck; the back, straighter than that of the rabbit; the pendulous tail; the form of the limbs with their hoofed feet; and the dense covering of fine long curly hair or wool.

Note particularly its mode of feeding. It manipulates the herbage with its fleshy lips, grasps it with the front of the jaws, and then breaks it off with a twist of the head. If it is engaged in masticating its food observe how the lower jaw is swayed from side to side.

Note further that the sheep does not plant the soles of its feet flat on the ground, but that it walks on the tips of its toes, the wrist and the ankle being both considerably above the ground. Animals that support themselves in this manner on their toes or *digits* are called *digitigrade*.

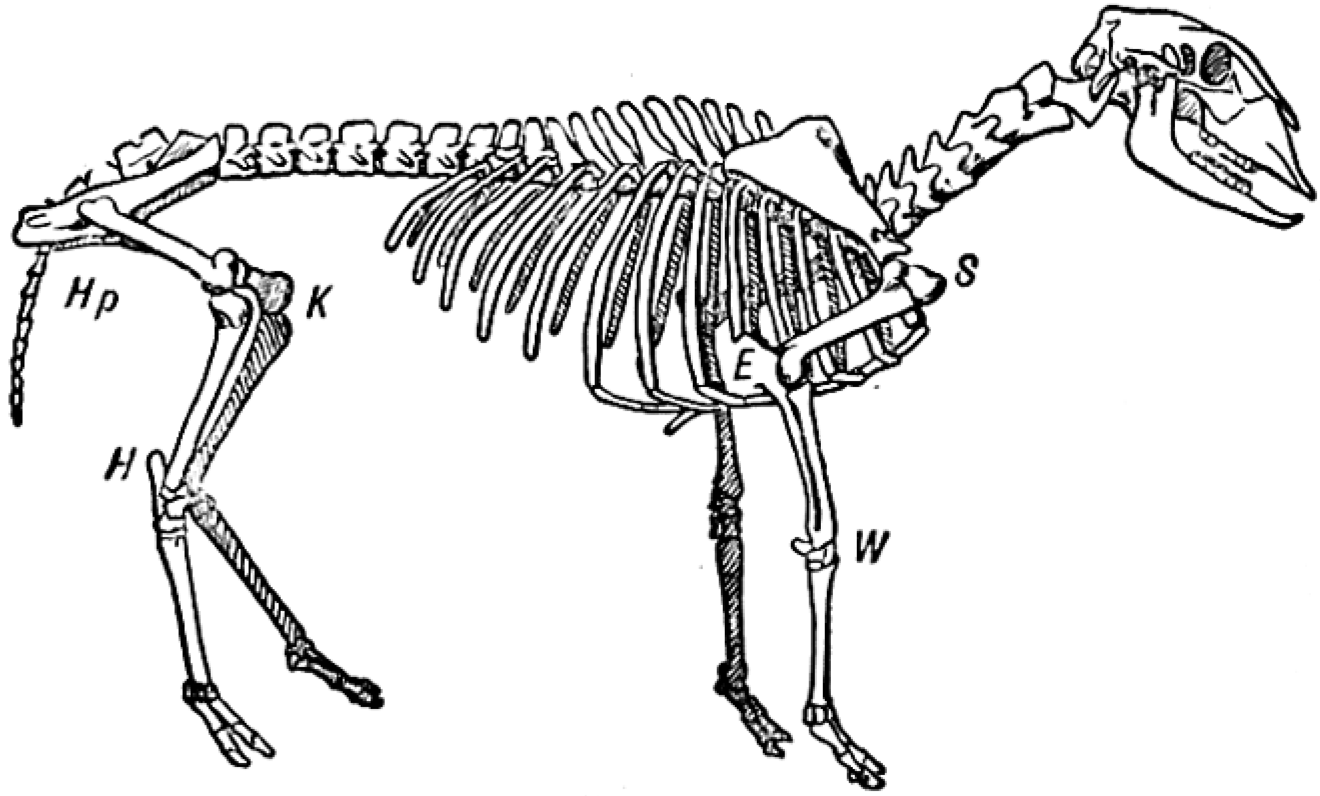

Fig. 155.—The Skeleton of the Sheep.
S, shoulder-joint; *E*, elbow; *W*, wrist; *Hp*, hip-joint; *K*, knee; *H*, heel.

The general arrangement of the bones of the skeleton is practically the same as in that of the rabbit, but important differences occur in the feet and the skull.

Procure a sheep's skull, preferably one with horns, from the butcher, boil it for a time, and then clear away all soft parts, including the brain, which can be removed by means of a bent wire. Wash it well, running plenty of water into the brain cavity, and then study it, making comparisons with the skull of the rabbit. Note particularly the eight chisel-like teeth in the front

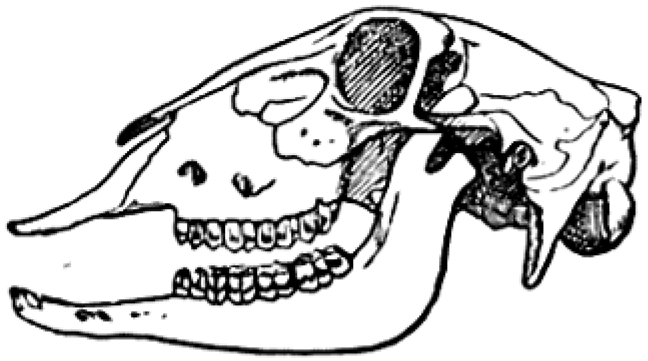

Fig. 156.—The Skull of the Sheep.

of the lower jaw, and the total absence of teeth in the corresponding portion of the upper jaw. Adjoining the cutting teeth of the lower jaw is a wide toothless gap, and next to this are six massive grinders, opposed by the same number of similar teeth above.

When the sheep is feeding it grasps the herbage between the front teeth of the lower jaw and the hardened gum of the upper, and then breaks it off. By this means a firmer hold is made than could possibly be obtained by grasping the vegetation between two sets of teeth. The broad grinders are used for mastication, and are admirably adapted for the effectual crushing of the food.

Put the lower jaw in its proper position, and note that it articulates with the skull in such a manner as to allow considerable lateral or side to side movement resembling the movement of the jaw as observed in the living sheep when chewing its food. Compare with the rabbit's skull.

Pull off the horns from the skull, and note that they are hollow cones of horny skin that ensheathe two conical masses of the frontal or forehead bone. In some varieties of the domestic sheep both sexes are horned, but in others the males only.

In order to study the limbs of the sheep the bones of the leg and the shoulder of mutton should be cleaned and examined; —both the "joints" should be ordered from the butcher with feet attached.

The shoulder girdle is represented only by the scapula or blade-bone, which is similar in form to that of the rabbit, there being no collar bone. The humerus is short and massive. The radius and ulna are two distinct bones, and there is no rotatory movement of the former round the latter. The elbow joint is a beautifully formed hinge, protected behind by an olecranon process as in the rabbit. Beyond the two rows of carpal or wrist bones are two large metacarpal or hand bones, each bearing a finger of three bones; and the two

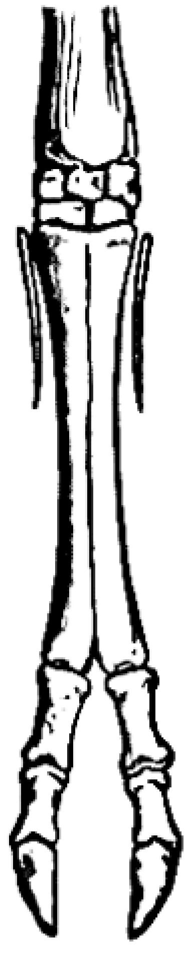
Fig. 157.—The Fork Foot of the Sheep.

finger-tips are ensheathed in a hoof of horny skin corresponding with the nails and claws of other mammals. On each side of the two large metacarpal bones is another very rudimentary one. It will be gathered from the above that what is commonly regarded as the front knee of the sheep is really the wrist, and that the elbow joint is within the trunk of the body. The latter is just on a level with the middle of the sternum.

In the hind limb the femur forms a ball-and-socket joint with the very deep acetabulum of the hip bone, and a hinge joint with the tibia below. The latter is the knee joint, but it is practically within the trunk of the body; and it is protected in front by a small discoid bone called the knee-cap or patella. Below the tibia is the "hock" or ankle joint, composed of five bones. The structure of the hind foot is similar to that of the fore foot.

The sheep is one of the *Ruminants*—mammals that are distinguished by their habit of "chewing the cud." This division of the mammals includes, in addition to sheep, oxen, goats, deer and camels. The ruminants are, as a rule, animals of tender flesh, and are on this account the favourite prey of the carnivorous mammals. Since they are all herbivorous in habit, they are compelled to take a great bulk of food, which can only be found in open places; hence in the wild state they are exposed to the attacks of their enemies as long as they are feeding. But this danger is reduced to a minimum by the peculiar nature of their stomach, which is so constructed that they are enabled to store up a large amount of food that has been swallowed without mastication, and then, on retiring to a sheltered place, to return it, a little at a time, to the mouth for mastication. This constitutes the process known as "chewing the cud."

The stomach of the sheep (Fig. 159) consists of four compartments, called respectively the *paunch*, the *honey-comb*, the *manyplies*, and the *digestive stomach*. The food is first swallowed, with abundance of saliva from the mouth, into the paunch, which is very large, and capable of storing a great bulk of food. It then passes into the honey-comb, so called because its lining membrane is divided up into a number of little chambers, and here the food is separated into pellets for chewing. It passes from the honey-comb, through the œsophagus, into the mouth, where it is masticated at leisure and still further mixed with the digestive saliva, after which it is re-swallowed and conducted through a different channel to the manyplies, so called because its lining membrane is drawn up into a number of parallel ridges. In the manyplies it is still further mingled with digestive juices, and is then passed into the fourth stomach, where the process of digestion is continued. The intestine, of course, conveys the food from the fourth stomach. It should be known that the stomachs of ruminants are prepared for food, and sold under the name of tripe. We mention this fact in order that the reader may know where to procure specimens for the observation of the peculiar arrangement of the linings of the different compartments.

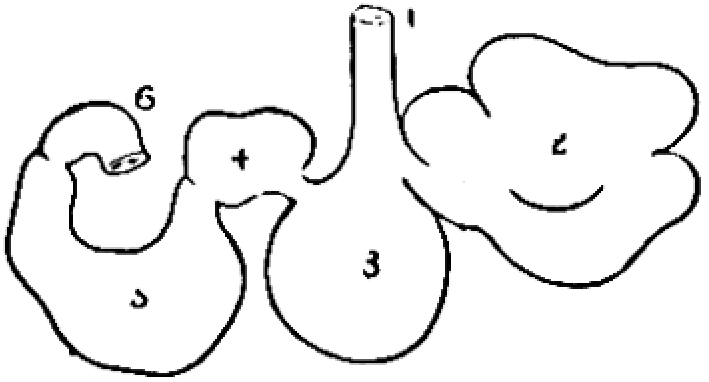

Fig. 159.—The Stomach of the Sheep. 1, Œsophagus; 2, 3, 4, and 5, Compartments of the Stomach; 6, Commencement of the Intestine.

The eye of the sheep should also be obtained from the butcher for examination. In it observe the large round black *pupil*, surrounded by a coloured ring—the *iris*. Note also the general toughness of the eyeball, which is white with the exception of the parts referred to above; and the portions of six muscles by means of which the ball is rotated in its socket. The pupil is simply a hole in the iris to admit light into the interior of the ball, and the iris is a muscular curtain by which the size of the pupil is regulated in accordance with the intensity of the light. The action of the muscles is not under the control of the will, but the light itself is the stimulus that causes the change. When the light is strong the circular muscles of the iris contract, thus reducing the pupil; but when the intensity of the light is less these muscles relax, and permit a set of radiating fibres to enlarge the pupil.

The ox, cow, goat, and deer all closely resemble the sheep in general structure and habits. All are digitigrade animals, with a skeleton closely resembling that shown on page 184; and all have the same arrangement of teeth. They also take their food in the same manner, have a similar digestive apparatus, and chew the cud.

The external features that distinguish these domestic animals should be carefully noted by the student, particularly the nature of the covering of hair or wool, the form and uses of the tail, and the characters of the horns. As regards the last-named, it will be observed that the horns of the ox and the cow are directed forwards, and are smooth, while those of the goat and the sheep are angular and wrinkled. The deer has solid horns which are often branched. These are termed antlers, and are annually shed and renewed, each new growth being generally larger and possessing more branches than its predecessor.

THE PIG.

The ruminants form an important division of the *ungulates* or hoofed animals, which include the pig, the horse, and their allies.

All these ungulates are similar in that they use their limbs for progression only, and never for prehensile purposes. They have no collar bones, nor do any of them possess claws, but each toe is covered at the tip by a hoof of hard, horny skin. They are usually animals of large size, and in all the cheek teeth or molars are broad, with transverse ridges of enamel.

We shall now study the general characters of the domestic pig, and the reader should carry out his observations direct from the living animal, following the suggestions given below.

First note the general form of the body, with its scanty covering of bristly hairs together with a slight woolly under-fur.

The neck is very short and thick, and the elongated head is carried low. The external appendages of the ears are large, and are usually pendant and flapping; and the muzzle terminates abruptly in a mobile snout, in front of which is a naked disc in which the nostrils are placed. An examination of our diagram of the skull (Fig. 159a) will show that the flexible snout is supported by a separate bone.

Note that the pig walks on the tips of its digits, after the manner of the ruminating animals. Its feet are narrow, and each has four well-formed toes, all of which have distinct metacarpal or metatarsal bones, corresponding, respectively, with the bones of the palms of our hands and the insteps of our feet. The two inner toes are longer than the others, and are brought nearer together by the flattening of their inner surfaces. These alone are used for support, and are tipped with well-formed hoofs. The two outer toes, though perfectly formed, do not touch the ground in walking, and are placed farther back than the main pair. The bones of the foot are represented in Fig. 159; which should be carefully studied, and compared with the diagrams of the feet of the other mammals described.

The student should also observe the positions of the main joints of the limbs—the shoulder and elbow, and the hip and knee—the positions of which may be located in the living animal as it walks. Observe also the long cylindrical tail, with the tuft of hairs at its extremity.

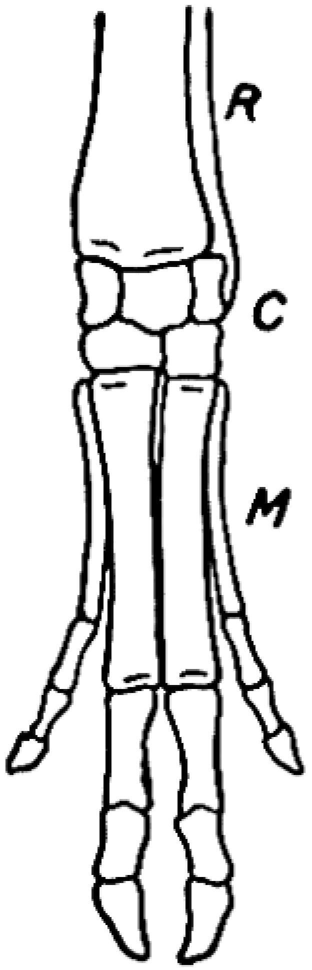

Fig. 159.—Foot of the Pig.
R, radius and ulna; *C*, carpus or wrist; *M*, metacarpal bones, to which the toes are attached.

Pigs are omnivorous feeders, partaking readily of both animal and vegetable foods, which are often devoured eagerly when in an advanced stage of decomposition. They push their powerful, mobile snouts into the ground in search of roots and grubs; and, in the wild condition particularly, attack and devour any small mammals they are able to secure.

They are not cud-chewing animals, and possess simple stomachs, much resembling that of the human body.

The nature of the teeth of the pig may be studied with the aid of our diagram (Fig. 159a), but better still by the examination of the head of the animal as supplied by the butcher. There are six incisor or biting teeth in the front of each jaw. Behind these are the tusk-like canines, and then the molars or grinders with irregular crowns adapted for the mastication of food. The upper canines curve *upward*, and are worn away on the outer side by friction against those of the lower jaw. These canines are much more strongly developed in wild species; and, growing continuously, often become formidable weapons. If one tusk is broken, the opposite one continues to grow, and often reaches such a length that it penetrates the skull, and causes the death of the animal.

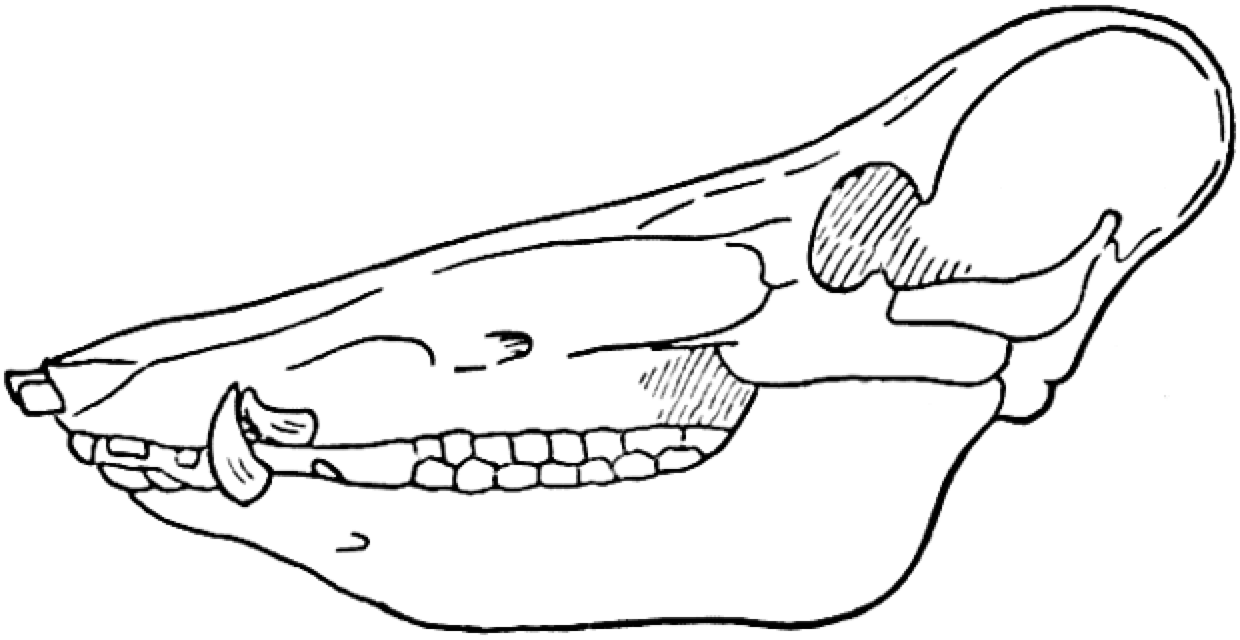

Fig. 159a.—Skull of the Pig, showing the nature of the teeth.

THE HORSE AND THE DONKEY.

There are yet two domestic hoofed animals to be considered—the horse and the donkey. These are so similar in their general build that we will first note the features common to both.

Like the hoofed animals already described, both the horse and the donkey walk on the tips of their toes, and the general structure of the skeleton is the same except that there is only one toe to each foot, and the tip of this one is enclosed in a large, solid hoof. The single toe is attached to a thick metacarpal bone, but on each side of the latter is a thin, splint-like, metacarpal—the remnants of two other toes. Also the radius and the ulna of the fore leg grow into one below, while the tibia and fibula of the hind leg have grown together throughout their length.

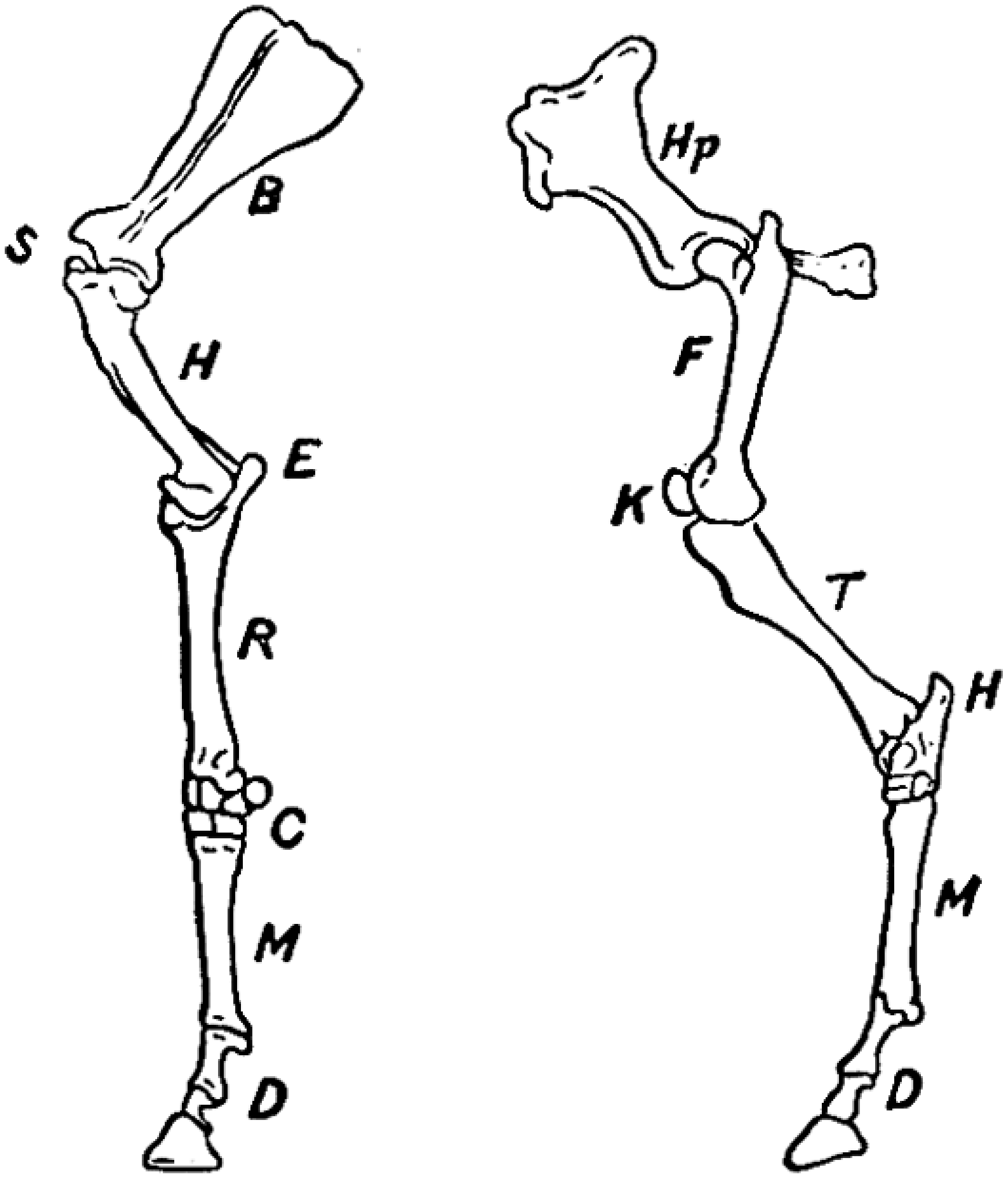

Fig. 160.—Bones of the Fore Limb (left) and the Hind Limb (right) of the Horse.

B, shoulder-blade ; *S*, shoulder-joint; *H*, humerus; *E*, elbow-joint; *R*, radio-ulna; *C*, carpus or wrist; *M*, metacarpus; *D*, digit or toe; *Hp*, hip-bone; *F*, femur; *K*, knee-joint; *T*, tibio-fibula; *H*, heel.

Both the horse and the donkey are purely herbivorous, and are provided with teeth adapted for biting and crushing vegetable food. There are six incisor teeth in the front of each jaw, and these are peculiar as regards the arrangement of the enamel, which is folded inward on the summit of the crown, while the hollow thus formed is filled up with a softer bony substance.

The canine teeth are very small, and behind them is a large gap which, in the harnessed animal, receives the bit. The cheek teeth or molars have very high crowns, with enamel arranged in complicated folds; and the depressions between the ridges of enamel are quite filled up with bony substance, so that the tops of the crowns are flat, thus forming efficient masticators.

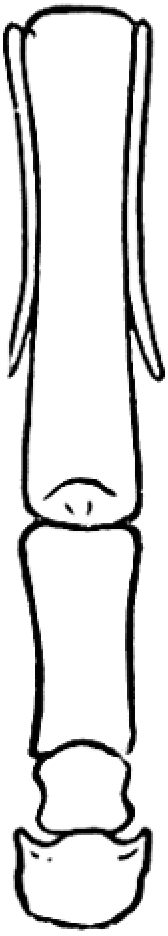

Fig. 161. Bones of the Foot of the Horse, showing the two splint-like metacarpal bones.

In both the animals the position of the principal joints of the limbs should be observed. Thus, it should be noted that the joint commonly regarded as the knee is really the carpus or wrist, while the elbow-joint of the fore limb and the knee-joint of the hind leg are both close to the trunk of the body, on a level with the breast-bone.

As regards the differences between the horse and the donkey, we note that the mane of the former is flowing, while that of the latter is erect; that the head of the former is smaller in proportion than that of the latter; and that the tail of the horse is hairy from its base, while that of the donkey has no long hairs on its upper part. Further differences are to be observed in the hoofs, which are considerably narrower in the donkey than in the horse; and there are wart-like "*callosities*" on the inner surface of the fore limb of both horse and donkey, just above the wrist, also one on the inner surface of the hind limb of the horse only, a little below the "hock" or heel-joint.

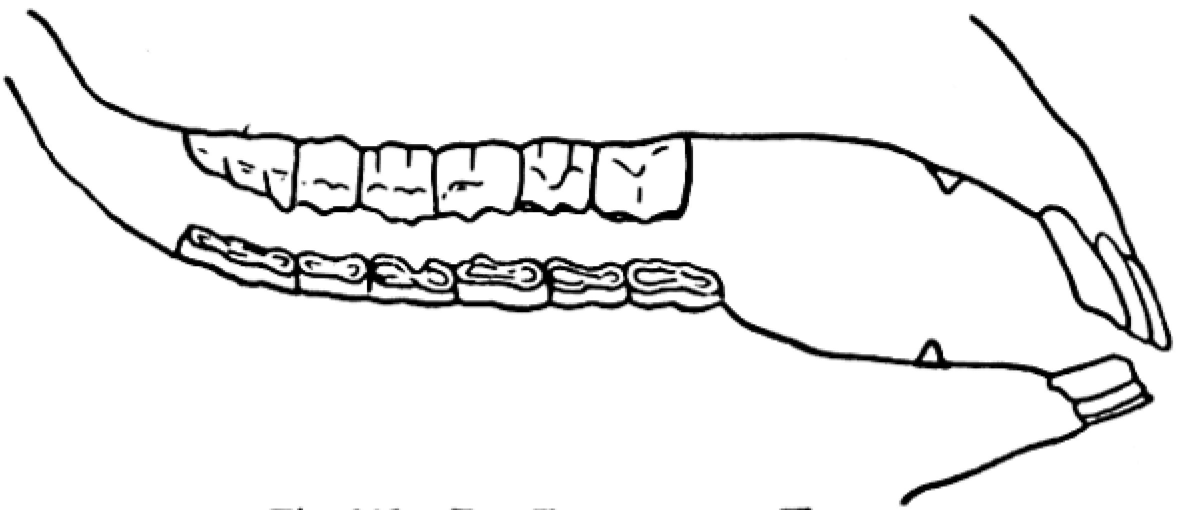

Fig. 162.—The Teeth of the Horse

THE CAT AND THE DOG.

The student has, by this time, carried out so many observations under guidance that he may be safely trusted to search out the general external features of the above domestic animals with but little assistance; hence we shall do no more than call attention to a few of the more important characteristics, giving explanations where it may appear necessary.

After observing the general form of the head, neck and body, the appendages of the ears and their motions, the general form of the limbs, and the dense fur of the cat as compared with the usually less dense hair of the dog, note more particularly the form of the eyes and their protective lids and lashes. In the dog the pupil is round, and though it is reduced in size when turned towards a strong light, it still maintains this shape. The pupil of the cat's eye, on the contrary, is large and round in a very weak light, becomes elliptical as the light becomes stronger, and is reduced to a mere vertical slit when the light is very intense.

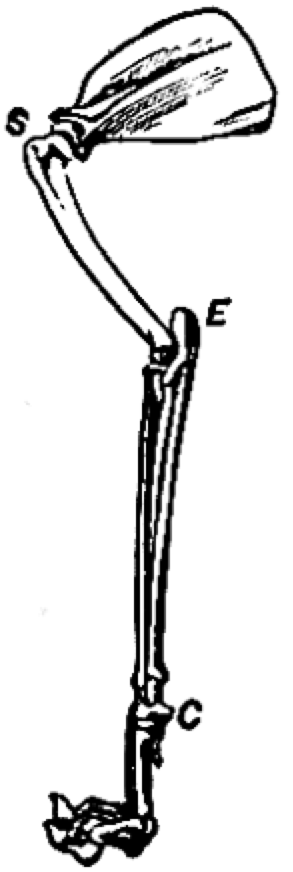

Fig. 160.—Bones of the Fore Limb of the Cat.
S, Shoulder Joint; E, Elbow; C, Carpus or Wrist.

The tails of both cat and dog do not seem to perform any very important function, but are chiefly remarkable as a means by which the animals can give expression to their emotions.

Note that both cat and dog are digitigrade animals; that is, they both walk on their toes, and do not plant the soles of their feet on the ground. The arrangement of the bones of the limbs is very similar in the two animals, and our illustration of the limbs of the cat will show how these are constructed. In both cases the radius does not rotate round the ulna, and in both the toes are distinct and terminate in claws. The claws of the cat, however, can be withdrawn within sheaths of the skin when not in use, and thus they are prevented from being worn away and blunted as the animal walks; but the claws of the dog, not being retractile, are always worn and blunt.

Another special feature of the cat's feet is the presence of very soft pads that enable the creature to approach its prey silently. The cat is also greatly assisted in its movements, when in the dark, by the very sensitive bristles of its "whiskers."

If possible, the student should procure the skulls of the cat and dog for the special study of the teeth, but failing this he will be able to observe the teeth fairly well in the mouths of live docile animals. This done, the mode of feeding must be closely watched in order to note how the arrangement and form of the teeth are peculiarly adapted to the habits of the animals.

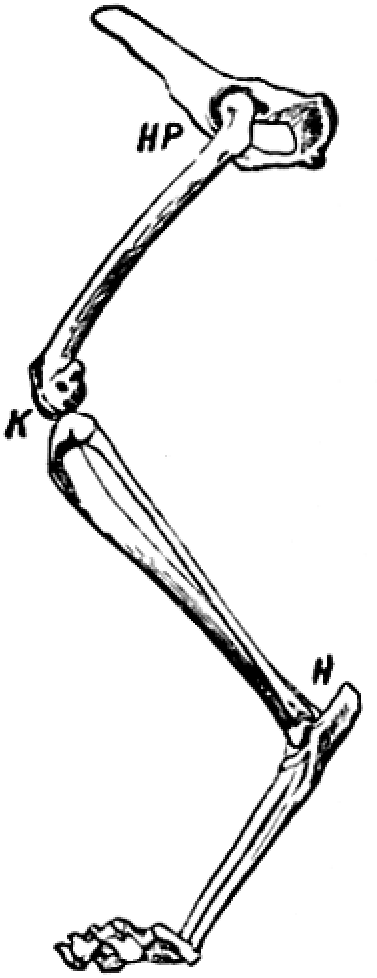

Fig. 161.—Bones of the Hind Limb of the Cat.
HP, Hip Joint; K, Knee; H, Heel.

In the cat's mouth we observe six small incisor teeth in the front of each jaw. Behind these, on each side, is the long conical canine tooth so characteristic of the carnivorous mammals; and then follow the molars. The canine teeth are peculiarly adapted for seizing and tearing the flesh of the prey; and the molars, of which there are four on each side of the upper jaw and three in the lower, are not adapted for chewing or masticating as in the rabbit, but for cutting the fleshy food.

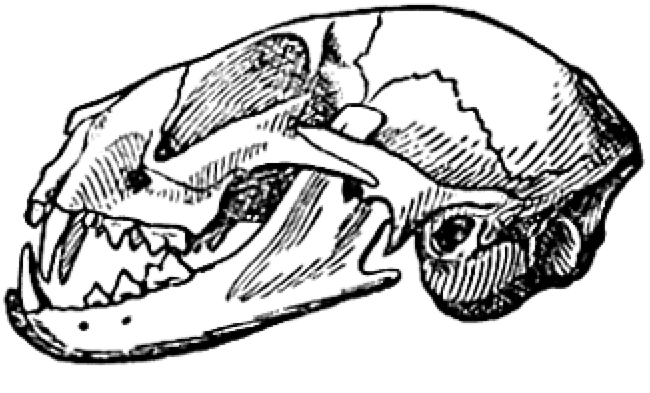

Fig. 162.—Skull of Cat.

To more thoroughly investigate the function of these teeth put the lower jaw of the cat's skull in its proper position, and note that it articulates with the temporal or temple bones in such a manner that it is capable of a vertical movement only, and no sliding movement is to be observed as in either the sheep or the rabbit. Now move the lower jaw up and down as is the habit of the animal when feeding, and note that the conical summits of the molars do not *meet*, but that they *slide* one over the other with a scissors-like action.

In confirmation of the above statements watch the cat as it feeds. It will sometimes seize the flesh by means of its long canines, and attempt to tear it; but the most characteristic movement is shown in the cutting action of the molars, the head being held on one side for the purpose.

The tongue is also brought into play during the feeding, for this organ is rendered so rough on the upper surface by the presence of numerous little hard projections with their points turned backward, that it is very effectual in the cleaning of bones. To fully appreciate this dip your fingers in milk and allow the cat to lick it off.

The arrangement and form of the teeth in the dog is practically identical with that of the cat. The number is also the same, except that the former has a larger number of molars—six on each side of the upper jaw and seven in the lower. The dog also feeds much in the same manner, though the cat is more purely carnivorous, and more commonly hunts and kills its prey. Further, the tongue of the dog is smooth, and not adapted for licking bones. Another use of the tongue of both animals should be observed as they drink.

Both cat and dog are members of the *Carnivores* or flesh-eating mammals, all of which are distinguished by the possession of jaws and teeth as above described, and by their long and usually sharp claws. The order includes, in addition to the species chosen, the lion, tiger, leopard, lynx, hyæna, weasel, otter, skunk, bear, badger, and many other animals. Some of them—the bear and badger for example—are plantigrade; that is, like the rabbit, they walk on the soles of their feet.

THE CLASSIFICATION OF MAMMALS.

We have briefly considered types of four of the orders of the class Mammalia—Rodents, Ruminants, Carnivores and the Hoofed Animals, but it may be interesting to the student if we append a general outline of the classification of the group for reference. It must be understood, however, that the table given below is by no means complete, but simply includes the orders that contain British and the most familiar of the foreign species.

MAMMALIA.

(ANIMALS THAT FEED THEIR YOUNG WITH THEIR OWN MILK.)

Order 1.—*Marsupialia.*—Animals which are born in a very rudimental or imperfect state, and are sheltered by the female parent in an external abdominal pouch. Example—the Kangaroo.

Order 2.—*Edentata.*—Animals with no incisor teeth, that feed on insects, other small creatures, and carrion.—Anteaters and Armadillos.

Order 3.—*Ungulata* or Hoofed Animals.—Herbivorous mammals in which each toe is enclosed in a broad hoof of horny skin.—Horse, Zebra, Ass, Tapir, Rhinoceros and Swine.

Order 4.—*Ruminantia.*—Mammals that chew the cud, including the animals named on page 186.

Order 5.—*Cetacea* or Whales.—Marine mammals in which the fore limbs are fin-like, and the hind limbs very rudimentary.—Whales, Dolphins, and Porpoises.

Order 6.—*Pinnipedia.*—Aquatic mammals with four fin-like limbs. —Seals and Walruses.

Order 7.—*Carnivora.*—Flesh-eating mammals, including those given on page 195.

Order 8.—*Rodentia.*—Gnawing animals. Examples named on page 179.

Order 9.—*Proboscidea.*—Mammals provided with a proboscis or prolonged prehensile snout.—Elephant.

Order 10.—*Insectivora.*—Small burrowing mammals that feed on insects and worms.—Hedgehogs, Shrews, and Moles.

Order 11.—*Cheiroptera* or Finger-winged mammals.—Bats.

Order 12.—*Primates.*—The most highly-organised of animals, with opposable thumbs, collar bones and flat nails.—Monkeys and Mankind.

QUESTIONS.

1. Give a brief description of the external characters of any British mammal, noting particularly its external covering, its eyes, the form of its limbs, and the nature of the tail.

2. Point out the chief differences in structure and function of the hind limbs of (1) the rabbit, (2) the sheep, and (3) the cat.

3. Compare the fore feet of the sheep and the cat, and show how each is adapted to the habits of the respective animal.

4. Describe the arrangement of the teeth, and any other peculiarities of the mouth, of a rabbit. What is the food of the rabbit, and how is this food masticated?

5. Describe fully what movements you observe as you watch a sheep taking its food. Also explain the reason for the various movements noticed.

6. Give a description of the teeth of a cat or dog. Why does a cat hold its head on one side when feeding?

7. What are the principal features by which we may distinguish between the horse and a ruminant?

8. Explain the terms "plantigrade" and "digitigrade" as applied to mammals. Illustrate your explanation by reference to domestic animals.

CHAPTER XIII.

PHYSIOLOGY.

ELEMENTARY PHYSIOLOGY.

IN former divisions of this book we have described the general arrangement of some of the more important muscles and viscera of vertebrate types, and have incidentally referred to their functions in some cases. In this, our concluding division, we shall deal more particularly with the disposition and functions of the viscera, taking the human body as our type and referring, here and there, to the more striking differences to be observed in the lower vertebrates.

It should be borne in mind, however, that the mammals do not present any very essential differences (at least as far as our purpose is concerned) in the arrangement and functions of their internal organs, and consequently, though our descriptions will apply more particularly to the human body, the statements made may be confirmed by the examination of any one of them. Hence we strongly recommend the student to repeat at this stage the dissection of the rabbit or any other small mammal, and so verify, as far as possible, the facts given.

1. THE BODY-CAVITY AND THE VISCERA.

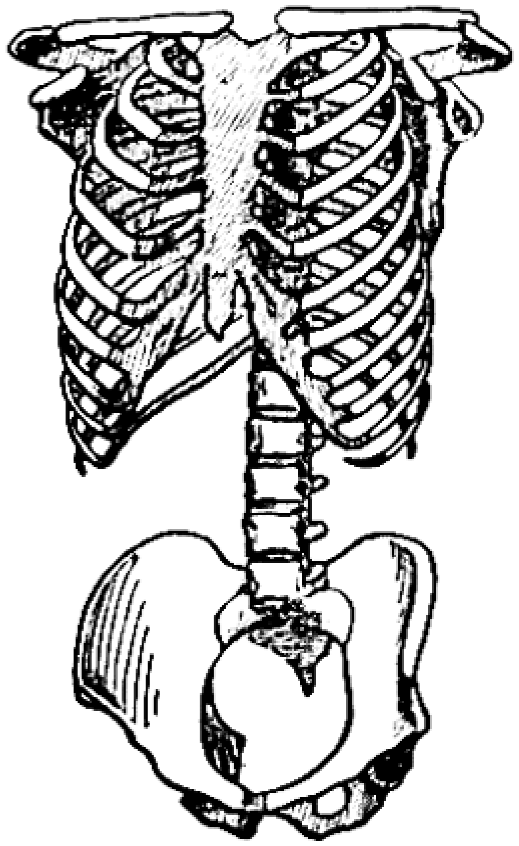

Fig. 166.—THE BONES OF THE HUMAN TRUNK.

In the first place we must become acquainted with the nature of the general body-cavity and the structure of its walls. The human vertebral column consists of thirty-three vertebræ, all of which are separate and distinct bones with the exception of those which form the sacrum —the portion that is wedged between the two hip-bones.

The neck is formed of seven *cervical* vertebræ, and the back of twelve *dorsal* bones. The latter bear the twelve pairs of ribs, which are jointed to the column in such a manner that they can be slightly raised and depressed in front. Five *lumbar* vertebræ form the loins; and then follows the *sacrum*, formed of five vertebræ grown together, below which are four separate small bones that correspond with the tail vertebræ of other mammals.

The first seven pairs of ribs are connected with the broad flat *sternum* or breast-bone by masses of cartilage. The next three pairs are similarly connected with the ribs above them; and the eleventh and twelfth pairs are called the free or floating ribs, not being connected with the bony framework in front except by soft muscular tissue.

The collar bones (*clavicles*) and the hip bones, though properly to be considered as parts of the upper and lower limbs respectively, will be included here with the bones of the trunk proper, since they are so closely associated with the build of the framework of the body cavity. The former are curved bones passing from the top of the breast-bone to the shoulders, and may be felt at the root of the neck in front. The hip bones, together with the sacrum behind, form a large basin-like cavity that contains the lower organs of the abdomen.

All the bones and cartilages above mentioned, excepting, of course, the bones of the neck, form part of the wall of the general cavity of the body, the remainder being composed of muscles and their tendons. Thus, between the ribs there are the *intercostal muscles;* while the whole sides and front of the abdomen are formed by sheets of muscle connected by sheet-like tendons.

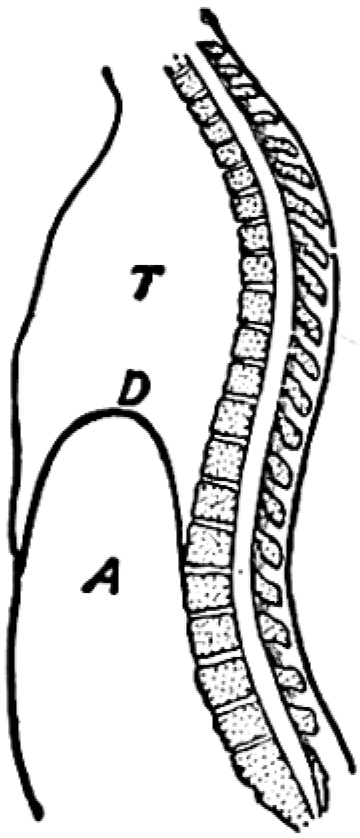

Fig. 167.—The Visceral Cavity of the Human Body. T, Thorax; A, Abdomen; D, Diaphragm.

The great visceral cavity is divided into two distinct portions by a *diaphragm*, which, as we may see in the rabbit, is made up of a central sheet of tendon, from which muscular fibres pass to the bones (back-bone, ribs and sternum) on all sides. The upper division is the air-tight thorax, and the lower is the abdominal cavity.

In the thorax are only the heart and great blood-vessels, the œsophagus, and the lungs, together with the lower portion of the trachea and its branches. These completely fill the cavity, the elastic lungs being inflated with air and kept stretched by the pressure of the atmosphere acting through the trachea. The heart is situated almost in the middle of the thorax, with its point or apex turned downwards to the left and resting on the diaphragm (Fig. 168).

In the abdominal cavity are the liver, stomach and intestines, pancreas, spleen, kidneys, bladder, etc. The liver is close under the diaphragm, more to the right than the left. The stomach is more to the left side, and is partially covered by the left lobe of the liver. The œsophagus communicates with it immediately on passing through the diaphragm, and the small intestine commences at its right end. The pancreas is situated behind the lower part of the stomach, and the spleen at the left or larger end of the same organ. The kidneys are half embedded in the walls of the loins at the back of the abdomen, and each one sends a tube (*ureter*) down to the bladder, which receives its excretion and is situated in the front of the pelvis.

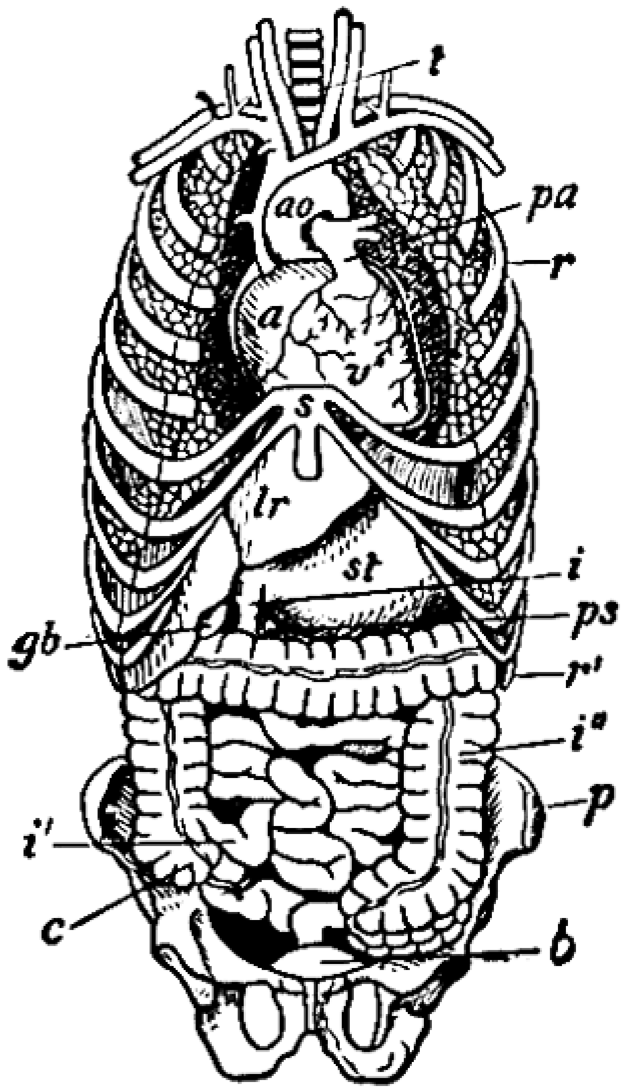

Fig. 168.—Diagram showing the General Arrangement of the Viscera of the Human Body.

t, Trachea; *r*, Ribs; *a*, Auricle of the Heart; *v*, Ventricle of the Heart; *ao*, A Great Blood-vessel—the Aorta; *s*, Lower portion of the Sternum; *st*, Stomach; *lr*, Liver; *gb*, Gall-bladder; *i*, Commencement of the Small Intestine; *i'*, End of the Small Intestine; *i''*, Large Intestine; *c*, Cæcum; *b*, Bladder; *p*, Pelvis or Hip-bone; *r*, The Fourth Rib; *r'*, The Eleventh Rib.

2. Waste, Repair, and Food.

During the growing period of the body additions are being constantly made to the various organs and tissues, the additional substance being derived by the conversion of food material into living matter. Food is equally necessary in the adult stage, for, apart from the matter required for the reproductive functions, the cells of the different tissues are constantly undergoing a process of breaking up or disintegration; each one, having completed its functions, becoming a little mass of dead matter that is to be transformed into carbonic acid gas, water, and other soluble material, by combination with oxygen, and thus changed to such a condition that it can be removed from the blood by the agency of the excreting organs.

Not only is food required for the above purposes, but it, or rather part of it, represents so much fuel for the maintenance of the high temperature of the body and the vast store of energy required for the performance of the functions of the various organs, especially of the muscles.

A considerable amount of the food that has been digested and absorbed into the blood never forms tissue of any kind, and therefore adds nothing to the weight or bulk of the body, but consists of complex compounds, obtained directly or indirectly from vegetable matter, the elements of which are held together by the energy originally derived from the sun. The compounds referred to are readily broken up into simpler materials by union with oxygen, the latent energy they contained being thus transferred to the system, mainly in the form of heat.

The food materials we take consist mainly of the organic substances just referred to, but we must also include with them certain inorganic or mineral compounds—principally the salts of lime (calcium carbonate and calcium phosphate) required for the hardening of the bones, and common salt (sodium chloride) and other soluble substances necessary for the maintenance of the proper density and functions of the blood.

Organic food substances consist of nitrogenous and non-nitrogenous compounds, the former containing the element nitrogen in addition to the carbon, hydrogen and oxygen present in both.

The nitrogenous compounds, including the legumen of peas and beans, the vegetable albumen of certain seeds, and the gluten of wheat, also the albumen, gelatin, myosin and chondrin of animal substances, are essentially tissue-forming foods, since they alone contain the nitrogen necessary for the building up of the protoplasm or living matter of the cells. Thus they are all-important for the formation of flesh or muscular tissue and other parts of the body. They are also concerned, to some extent, in the maintenance of the heat of the body.

The non-nitrogenous foods are separable into two well-defined groups—the carbo-hydrates and the hydro-carbons. The former include the starches and sugars that are derived so abundantly from vegetable sources, and similar compounds contained in smaller proportion in animal tissues. They all contain, in addition to carbon, the elements hydrogen and oxygen in the same proportion as they exist in water. The hydro-carbons include the oils of vegetable fruits and seeds and the fats of animals. In them the proportion of hydrogen, as compared with the oxygen, is very much higher than in water. The non-nitrogenous foods are principally concerned in the formation of fat and in the production of heat, the carbo-hydrates being more essentially the fat-formers, and the hydro-carbons the heat producers.

3. THE DIGESTIVE ORGANS AND DIGESTION.

Although we have already dealt with the general characters and disposition of the digestive organs, we shall, in the present section, refer to further particulars, more especially regarding internal structure and function; and, to render our brief description perfectly clear, the student should further examine the digestive organs of the rabbit or other small mammal, portions of which should be laid open, cleared of their contents and washed, and then inspected with the aid of a hand lens.

While the food is being masticated it is mingled with the saliva—an alkaline fluid that is poured into the mouth from several salivary glands. The principal of these glands are a pair (*parotid glands*) situated below and in front of the ears, another pair (*submaxillary glands*) under the lower jaw on each side, and a third pair (*sublingual glands*) under the tongue. The saliva contains a ferment (*ptyalin*) which has the power of converting insoluble starch into a soluble sugar, thus rendering it ready for absorption into the blood. By the combined mechanical action of the teeth and the saliva, aided further by the muscles of the cheek and tongue, the food is softened, collected into a mass, and then turned backward into the *pharynx*—a cavity at the back of the mouth—to be swallowed.

The first part of the act of swallowing is performed by the muscles of the pharynx, which contract on the food and press it down into the œsophagus. At the same time the lower portion of the pharynx, together with the enlarged upper part of the trachea (called the larynx) attached to it, are both raised, and the food is pressed on a raised elastic cartilaginous lid (*epiglottis*) that surmounts the larynx, thus forcing the lid down on the opening of the air-passage (the *glottis*), and so preventing the food from "going down the wrong way." On entering the œsophagus, which is a soft muscular tube attached to the back of the trachea, the food is pressed down into the stomach by the successive contraction of the circular muscular fibres in its walls. Thus the whole act of swallowing is quite independent of the action of gravitation, being purely a muscular action.

In the stomach the food is kept in continual motion by the contraction of different sets of muscular fibres that form a considerable part of its thick walls; while, at the same time, a multitude of minute glands (*gastric glands*) pour on it another digestive fluid called the *gastric juice.* These glands form the greater part of the lining membrane of the stomach, and the membrane itself is drawn up into longitudinal folds, thus increasing the area of the glandular surface.

The gastric fluid is slightly acid, and contains a ferment (*pepsin*) which has the power of dissolving nitrogenous food substances. The digestive work of the stomach usually occupies a few hours, during which time the undigested portions are prevented from passing into the intestine by the contraction of a circular muscle that surrounds the entrance to the latter; and the contents of the stomach are eventually converted into a soft semi-fluid mass, consisting of the partially digested starchy foods, partly digested nitrogenous foods, and minute globules of fat set free from the fat cells by the digestion of their nitrogenous walls and of the nitrogenous connective tissue that bound the cells together.

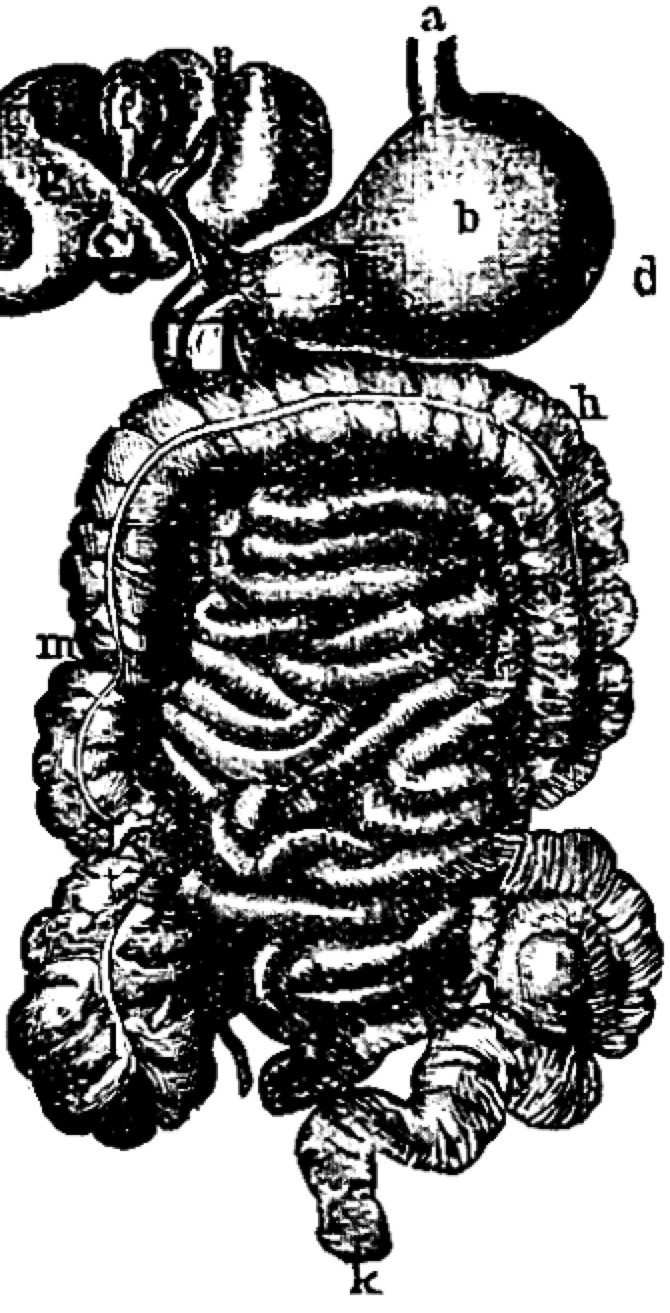

Fig. 169.—Diagram of the Digestive Organs of the Human Body.
a, Œsophagus; b, Stomach; c, Pancreas; e, Pyloric end of Stomach and commencement of Small Intestine; f, Gall Bladder; g, Liver; l, Cæcum; mh, Colon; k, Rectum.

As the gastric digestion nears its completion, the muscle guarding the entrance to the small intestine gradually relaxes, thus allowing all the contents of the stomach to pass out. Immediately on entering the small intestine the food is mingled with two other digestive fluids—the bile from the liver, and the pancreatic fluid from the pancreas, both of which are conveyed by ducts from the organs named, the ducts leading into the intestine at the same point.

The pancreatic fluid acts on both starchy and nitrogenous foods, while, in conjunction with the bile, it also digests fatty foods. In addition to these, still other digestive fluids are poured into the intestine from numerous small glands in the lining membrane of the tube; and the membrane is drawn up into transverse folds which not only increase the glandular surface of the tube, but also prevent the contents from passing too quickly through it.

The process of digestion is completed in the small intestine, through which the food material is slowly urged by the contraction of circular muscular fibres. The digested portions are absorbed by the soft lining membrane, not only of the small intestine, but of all parts of the digestive canal. In the large intestine the absorption is continued, until, at last, the undigested matter is left as a solid residue.

The nature of the junction of the small with the large intestine should receive special notice. It will be seen in our diagram that the latter commences in the lower part of the abdominal cavity, passing upwards to the liver, then to the left side under the stomach, and finally down on the left side, where it is bent on itself before leading into the *rectum* or straight gut. Observe, too, that the small intestine does not communicate with the large quite at the end of the latter, but so that a blind pouch-like portion, with a worm-like appendage (*vermiform appendix*), exists below it. This pouch is the *cæcum*, and we call special attention to it because in the rabbit and other rodents it is prolonged into a long blind tube; this being one of the characteristics of the rodents as a class.

We have already observed that the food, after being digested, is absorbed into the blood system, by which means it is conveyed into all parts of the body. Now, this absorption is carried on in two different ways. First, the soft lining of the stomach and intestines is richly supplied with minute thin-walled blood-vessels (*capillaries*) that are distributed close to the surface; and the digested nutrient matter can readily pass into them. Thus the nutrient substance is absorbed direct into the blood system for circulation through the body.

In this kind of absorption there seems to be no selective power on the part of the blood-vessels, all kinds of digested food passing somewhat freely through their walls. But, if we examine the interior of the small intestine with a hand lens. we find that its surface is practically covered with minute finger-like projections called *villi*, so small and so thickly set that they give the lining membrane the appearance of a fine velvet. In each villus there is a small vessel (*lacteal vessel*) which has the special power of absorbing digested fats, and the vessel is so named because it contains, during digestion, a fluid that is milky in appearance on account of the minute globules of fat that float in it.

All the small lacteal vessels of the villi unite to form larger vessels, and these eventually communicate with a duct that passes up the back of the thorax, immediately in front of the back-bone, and then enters a large vein at the root of the neck on the left side. Thus all absorbed food passes into the blood by one or other of these two means.

4. The Heart, Blood-vessels, and Circulation.

As an introduction to this portion of our subject we shall learn as much as possible concerning the heart and blood-vessels by the direct observation of these structures when taken from the body of some mammal. The heart and vessels of the rabbit would answer our purpose, but it will be considerably more convenient to obtain our specimens from the sheep.

(a) *Dissection of the Sheep's Heart.*

Procure, by previous order from the butcher, the heart of the sheep "in its bag," with all the vessels as long as possible. Examine the specimen carefully, noting especially the tough, loose bag (*pericardium*), supporting more or less fatty tissue, and connected with the great vessels at the top of the heart.

Slit open the pericardium and release the heart from it. Note the very smooth inner surface of the bag, and the similar outer surface of the heart itself. Observe also the attachment of the bag to the heart at the bases of the great vessels.

The pericardium is really a double membrane, consisting of the outer loose bag, together with the very thin smooth membrane that covers the surface of the heart itself. The latter can be peeled off, but not easily. The two layers form a closed cavity (pericardial cavity), and a small quantity of fluid (*serum*) between them acts as a lubricant, thus facilitating the movements of the heart.

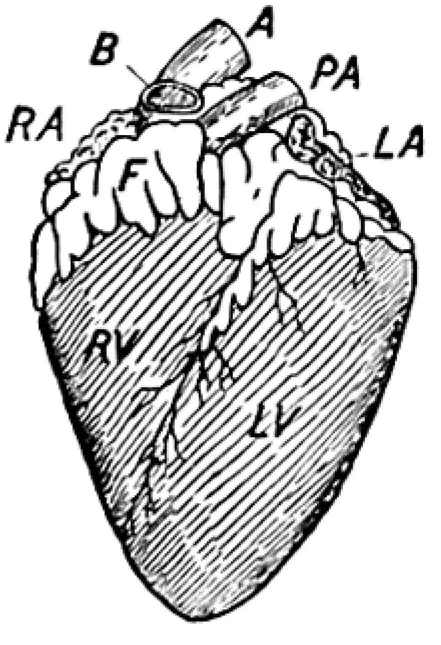

Fig. 170.—THE SHEEP'S HEART, VIEWED FROM THE FRONT.

RV, Right Ventricle; *LV*, Left Ventricle; *RA*, Right Auricle; *LA*, Left Auricle; *A*, Aorta; *PA*, Pulmonary Artery; *B*, Branch of the Aorta; *F*, Fat.

Cut away the whole of the outer layer of pericardium, and examine the external characters of the heart and its vessels. Note—

1. The general form of the heart—conical, with its apex or point at the bottom, and broad base, to which the vessels are attached, at the top.

2. The firm thick muscular walls of the greater portion.

3. Two earlike appendages (*auricles*) with thinner walls, lying flat on the base of the heart.

4. Blood-vessels passing round the base of the heart, in the groove between the auricles and the thick muscular portion.

5. Other blood-vessels branching from these, the two largest of which run downwards in grooves, one on each

side of the heart. These two grooves denote the position of the two sides of an internal muscular partition (*septum*) that divides the lower portion of the heart into two distinct cavities. These cavities are the *ventricles*, and we shall henceforth speak of the thick muscular mass of the heart as the ventricles, as contrasted with the corresponding ear-like auricles above.

6. Observe, by grasping the muscular walls between finger and thumb, that they are much thicker on one side of the two grooves than on the other. The thicker side is the left ventricle, and the thinner the right ventricle. Above these are the left and the right auricles respectively.

7. Having now distinguished between right and left sides, the front and back surfaces of the heart are easily determined. Note that the front surface is very convex, and the back flatter.

8. Observe the blood-vessels at the base or top of the heart. Note that some have thick white elastic walls, that open again immediately after they have been compressed. These are the *arteries*, that convey blood *from* the heart. Other vessels have thinner and comparatively inelastic walls, but are more or less supported by surrounding masses of fatty tissue. These are the *veins* that convey blood *to* the heart.

Remove any superabundant fat at the base of the heart; and, where small blood-vessels are visible, gradually trim down until you arrive at the large trunks from which they branch. The vessels are thus reduced to seven, and may be distinguished as follows:—

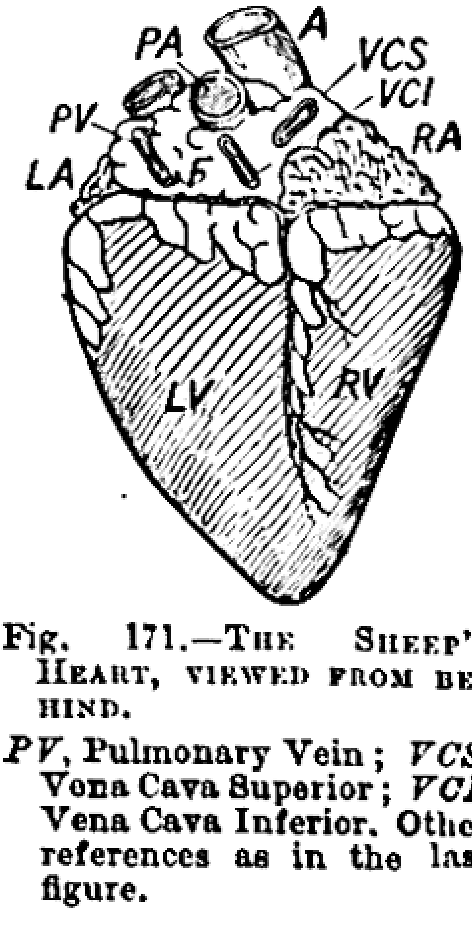

Fig. 171.—The Sheep's Heart, viewed from behind.

PV, Pulmonary Vein; *VCS*, Vena Cava Superior; *VCI*, Vena Cava Inferior. Other references as in the last figure.

9. A large artery (the *aorta*) at the middle of the base of the heart. Pass a blunt wooden skewer through it, and note that it communicates with the left ventricle. This artery conveys blood to the various parts of the body.

10. Two other arteries (right and left *pulmonary arteries*) that communicate with the right ventricle. They convey blood to the right and left lungs respectively.

11. Two large veins (right and left *pulmonary veins*) leading into the left auricle. They convey blood from the right and left lung respectively. (If the skewer passed into these vessels be directed downwards, it will pass through the auricle and then into the ventricle of the same side.)

12. Two very large veins at the back of the heart, communicating with the right ventricle. These are the *superior vena cava* that conveys blood from the upper parts of the body, and the *inferior vena cava* that returns blood from the lower parts. (Again note that the skewer may be made to pass through these vessels into the right auricle, and then, if directed downwards, into the ventricle of the same side.)

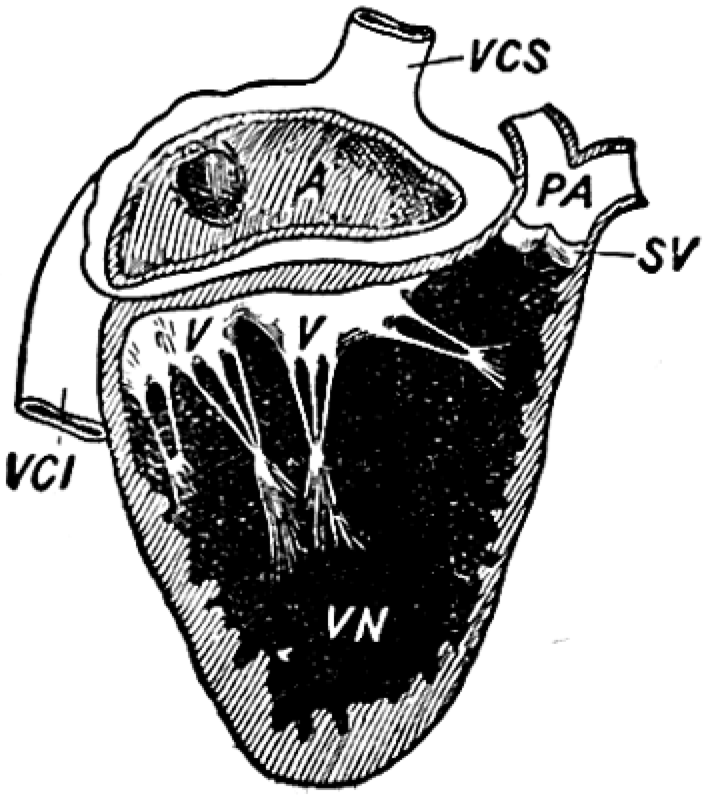

Fig. 172.—Interior of the Heart, Right Side.

A, Auricle; *VN*, Ventricle; *V*, Valve; *VCS*, Vena Cava Superior; *VCI*, Vena Cava Inferior; *PA*, Pulmonary Artery; *SV*, Semilunar Valves.

We have now to examine the interior of the heart, which should be opened in the following manner. Hold the organ with its front surface towards you, when you will have the right side turned towards your own left. Make a deep cut through the wall of the right ventricle, parallel with the groove already mentioned as marking the position of the internal septum, and about half an inch from it. Extend the incision quite to the top and bottom of the ventricle, turn back the wall of the cavity, remove any clotted blood that may be within it, and note—

1. The thickness of the wall and size of the cavity.
2. The large valve (*tricuspid valve*) formed of three

strong membranes attached round the circumference of the large aperture between auricle and ventricle, and held by strong cords of tendon that are attached below to projecting masses of muscle.

Cut the *left* auricle completely off, and note—

3. The size of the cavity.

4. Its walls, very thin and transparent in parts, but strengthened by a complicated arrangement of muscular masses.

5. The large opening leading into the left ventricle.

Pour a little water down into the ventricle, then press together the opposite walls of this cavity, and note—

6. The membranes of a valve are raised by the upward pressure of the water beneath.

7. The valve (*bicuspid valve*) is similar to that observed in the right ventricle, but consists of two membranes instead of three.

Open the left ventricle by making a very deep cut parallel with the anterior groove, and about half an inch from it. Observe—

8. The very thick walls, much thicker than those of the right ventricle.

9. The bicuspid valve, similar to the tricuspid on the right side, but much stronger in all parts, and having two cusps or membranes instead of three.

10. Cut off the right auricle, and note that its structure is similar to that of the left side.

Pass a skewer upward from the right ventricle, behind the valve, and out through one of the pulmonary arteries above. Follow its course with the knife-blade, and cut completely through to the artery, laying open the latter. Note—

11. Three half-moon-shaped pouches (*semilunar valves*) round the circumference of the *pulmonary trunk* which divides into the two pulmonary arteries. Note that the pouches, though thin, are very strong, and are so arranged that they would be filled out by fluid pressing on them from above; also, that when so filled, they would completely close the entrance to the artery.

Make a similar incision from the left ventricle, behind the valve, to the commencement of the aorta, laying open the vessel as before. Note—

12. Three similar and similarly arranged semilunar valves at the entrance of the aorta.

13. Two holes in the wall of the artery just *below* the semilunar valves. (These are the beginnings of two branches of the aorta, called the *coronary arteries.* They convey blood into the substance of the heart itself.)

(*b*) *The Circulation of the Blood.*

We have now to trace the course of the blood as it circulates through the complicated system of vessels that penetrate every part of the body with the exception of a few bloodless tissues such as the epidermis, the white of the eye, and cartilage. To do this we shall start with the blood entering the right auricle, and trace it until it reaches the same point again.

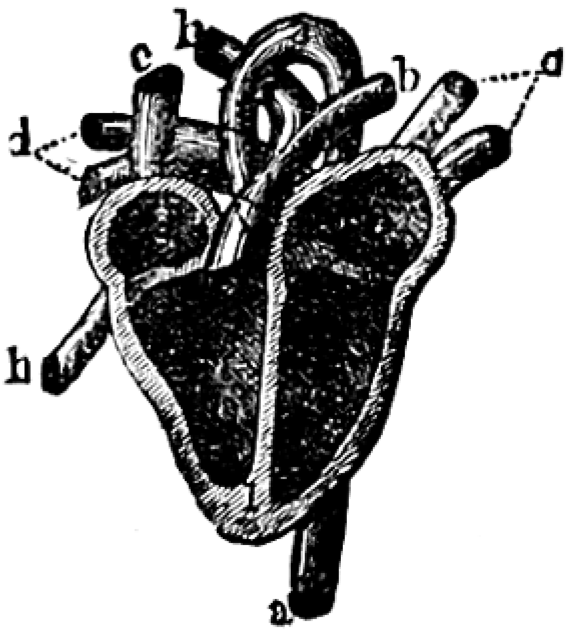

Fig. 173.—Diagram explaining the Course of the Blood.

c and *h*, Venæ Cavæ, conveying blood to the right auricle; *b*, Pulmonary Arteries, conveying blood to the lungs; *d*, Pulmonary Veins, taking blood from the lungs to the left auricle; *a*. Aorta, supplying blood to all parts of the body.

The blood that has just completed its circulation in the various parts of the body is returned to the heart by the venæ cavæ. On entering the right auricle it flows at once down into the right ventricle. The walls of the auricle contract to complete the filling of the ventricle, and the blood cannot pass backward into the great veins when this contraction takes place, for these are already full, and the blood they contain cannot flow back into the smaller veins, because the latter are provided with valves, resembling the semilunar valves of the heart, which prevent any backward flow.

Immediately after the contraction of the auricle is over the walls of the ventricle contract, pressing the blood upward against the under side of the cusps of the tricuspid valve and closing it. The passage into the auricle being thus closed, the blood is driven out through the pulmonary arteries into the lungs.

The arteries, on entering the lungs, divide and subdivide into smaller and smaller branches till at last they become microscopic *capillaries*, with exceedingly thin walls, surrounding the air-cells of the lungs. The capillaries then unite to form small veins, and these combine to form larger and larger veins till at last they give rise to the pulmonary veins.

The blood passes through this system of vessels, and is then conveyed by the pulmonary veins, which conduct it back to the heart, where it enters the auricle on the opposite side.

By the contraction of the left auricle the blood is driven into the corresponding ventricle. This contracts immediately afterwards, forcing the fluid into the aorta, the bicuspid valve being at the same time closed by the pressure below.

The aorta gives off branches to the upper parts of the body, and then the main tube arches over to the back of the heart, passes down through the diaphragm, and distributes branches to all the lower parts.

After the blood has passed through this system of arteries, it circulates through the minute capillaries of the various organs, and is then collected up by veins that convey it back to the right auricle through the venæ cavæ.

We have thus traced the complete circulation of the blood, and have at the same time observed that it has been made to pass through two distinct systems of vessels. The passage from the right ventricle through the lungs to the left auricle is called the *pulmonary circulation;* and that from the left ventricle through the body generally to the right auricle is the *systemic circulation.* All the blood of the body has to pass through these two systems successively in order to make one complete circulation.

Both circulations, however, are being performed at the same time. Thus, while some of the blood is passing through the pulmonary vessels, the remainder is traversing the vessels of the system generally. And, to this end, both auricles contract at the same moment, as do also the two ventricles immediately after.

In order to simplify our account of the circulation of the blood we omitted to include the action of the semilunar valves at the entrances of the great arteries. This will be dealt with now. When blood is forced from the powerful ventricles it enters the great arteries faster than it can flow into their branches. The arteries are therefore stretched; and, being elastic, they recoil on the blood, thus exerting pressure on it. This pressure, exerted above the semilunars, fills out the pouches of these valves, so preventing the blood from flowing back into the ventricles, and thus the recoil of the arteries assists the circulation by forcing the blood onwards after the contraction of the ventricles is over.

As the veins are larger and more numerous than their corresponding arteries the blood passes through them somewhat sluggishly. And having thin walls, the veins of the limbs may be closed at times by muscular or external pressure. To prevent the blood from passing backwards in the veins many of them, and more especially those of the limbs, are provided with valves resembling the semilunars. The presence of the valves may be proved by rubbing the veins of the arm downwards or from the heart. Blood is by this means pressed back on the valves, and their position is then revealed by the knotted appearance of the vein.

The great veins of the heart have no valves; nor have any of the arteries excepting the aorta and the pulmonary arteries.

A few other points in connection with the circulation of the blood must receive a passing notice.

If we press on a moderately large artery we can feel what is called the "*pulse.*" This is due to a *wave* of blood caused by the powerful contraction of the left ventricle. It does not in any way determine the velocity at which the blood flows, but, like a wave on the surface of water, has a motion independent of that of the water itself.

The *beating* of the heart is due to a tilting forward of its apex when the ventricles contract. It may be felt in the front of the chest, to the left of the sternum, and just under the fifth rib, this being the normal position of the apex.

The sounds of the heart are due to the vigorous contraction of the muscles of the ventricles and the sudden closing of the semilunars, the former producing a dull thud, and the latter a short and well-defined sound.

The circulation as described is that of mammals generally, and the blood-vessels mentioned may be traced by the dissection of any one of them. The main features in the circulation of the bird are also practically the same, the bird having the same kind of four-chambered heart and a very similar arrangement of the principal vessels.

In the frog, however, some important differences are to be observed. Thus, the heart of a frog has only three chambers—two auricles and one ventricle. The principal features of this heart, as well as the nature of the circulation, may be gathered from the accompanying diagram, aided by the following brief description.

The blood from all parts of the body is brought by the venæ cavæ into the right auricle. At the same time the left auricle receives the blood from the lungs. Both auricles contract together, and both propel the blood they contain into the one ventricle, which therefore contains a mixture of

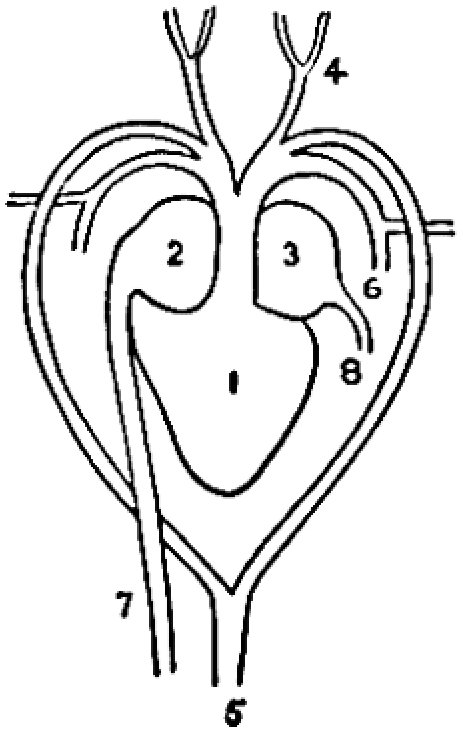

Fig. 174.—Diagram showing the Heart and Circulation in the Frog.

1 Ventricle; 2, Right Auricle; 3, Left Auricle; 4, Arteries supplying the Head; 5, Artery supplying posterior parts of the body; 6, Artery supplying the Lungs and Skin; 7, Great Vein bringing blood from posterior portions of the body; 8, Vein conveying blood back from the lung.

aerated and non-aerated blood. Then the ventricle contracts, forcing the blood into two great arteries, each of which immediately divides into three vessels. One of the three supplies blood to the fore parts, another sends blood to the lungs and the skin to be aerated, and the third supplies the other parts of the body.

Thus there are not two distinct sets of pulmonary and systemic vessels in the frog, and only a portion of the fluid is aerated at each circulation. It should be mentioned, however, that the structural arrangement of the ventricle is such that the two kinds of blood in it do not completely mix, the most impure being driven to the lungs and skin, the purest to the head, and the more or less mixed blood to the body.

5. The Blood.

Wind a piece of string tightly round a finger near the tip until the end is swollen and dark. Prick it with a fine needle, and apply the little drop of blood that oozes out to a glass slip. Cover it immediately with a cover-glass, then apply a gentle pressure with the needle to spread the blood out into a very thin film, and examine it under the high power of the microscope.

Observe that the blood consists of a colourless fluid in which float a multitude of minute round bodies (called *corpuscles*). Of these bodies there are two distinct kinds. One, called the red corpuscles because they give the red colour to the blood, consists of pale yellow discoid bodies, concave in the middle, and 1-3000th of an inch in diameter. The other kind are the so-called white corpuscles, which are globular masses of transparent protoplasm, resembling the amœba, and even exhibiting the same kind of movements. The white corpuscles are far less numerous than the red, there being only one of these to every hundred or more of the latter.

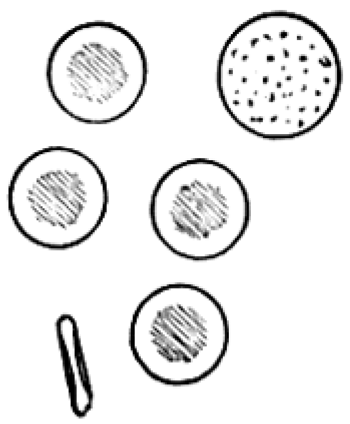

Fig. 175.—Human Blood as seen under the High Power of the Microscope. One of the Red Corpuscles is seen edgeways.

The fluid part of the blood consists of water in which is dissolved some mineral salts and nitrogenous organic matter. When blood is drawn it soon forms a clot. This is due to the fact that some of the nitrogenous matter it contains becomes converted into a semi-solid substance called fibrin.

Procure a little blood from a recently killed rabbit by making an incision into the left ventricle, allowing the blood to run into a bottle of moderate size. Note that the blood is of a bright red colour. Now prepare some carbonic acid gas by the action of dilute hydrochloric acid on pieces of marble contained in a bottle fitted with a cork and leading tube. Pass the gas into the bottle, then cork it up and set aside. Note that the colour of the blood is gradually turned to a dark purple.

Obtain a second portion of blood from the right ventricle, and pass it into a bottle as before. Note that it is of a darker purplish colour. On exposure to air the colour brightens somewhat, but soon becomes bright red if oxygen gas (prepared by heating a mixture of potassium chlorate and manganese oxide in a small flask) be passed into the bottle.

The red corpuscles of the blood contain a colouring matter (*hæmoglobin*) which absorbs oxygen and holds it in feeble chemical combination. When thus in combination with this gas it is of a bright red colour. If, on the other hand, the oxygen is liberated and the blood is charged with carbonic acid gas, the hæmoglobin becomes of a darker and duller colour.

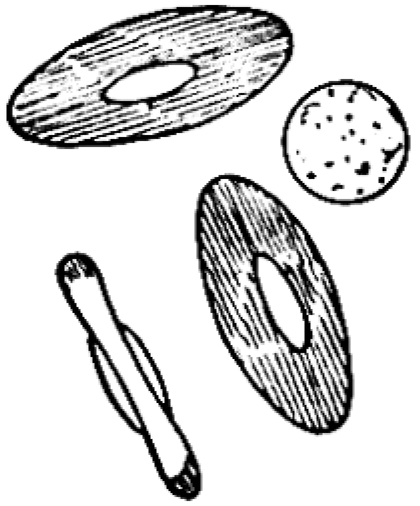

Fig.176.—The Blood Corpuscles of the Frog, highly magnified.

Obtain a little blood from the ventricle of a recently killed frog, and examine it under the high power of the microscope. Note the very large oval nucleated red corpuscles, much larger than those of the human blood. Also the much smaller and fewer colourless corpuscles.

Procure also a drop of blood from a bird, and examine it in the same manner. Note that it consists of a colourless fluid, in which float numerous very small oval nucleated red corpuscles, and a comparatively small number of colourless corpuscles.

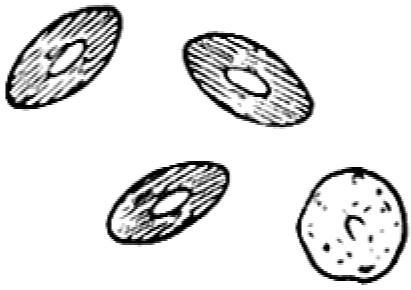

Fig. 177.—The Blood Corpuscles of a Bird, highly magnified.

6. The Lungs and Respiration.

Remove the trachea and lungs, intact, from a rabbit, or procure the same organs of the sheep or other mammal. Blow down the trachea to inflate the lungs, and note how the stretched lungs expel the air by their elasticity when the force is withdrawn. Place the lungs on water and note how they float.

Observe the general form of the lungs when not inflated. Inflate them with air, and note how they now assume the form of the thorax from which they were removed. Observe the space previously occupied by the heart, and the concave under-surface that touched the diaphragm. Note also that each lung is partially divided into parts (called *lobes*), and observe the pulmonary arteries and veins at the inner surfaces of the upper part.

Turning now to the trachea, note the enlarged upper portion (the *larynx*) that contains the vocal cords, the trachea proper, and the two large branches (*bronchi*) that enter the lungs. Observe that all the parts are composed of rings of gristle (cartilage) held together by a softer tissue. The rings, with one exception, are incomplete on the posterior side, where the ends are connected by the softer tissue.

The soft spongy tissue of the lung may be gradually dissected away from the branches of the trachea, when it will be seen that each lobe of the lung receives a separate branch of the trachea, which continues to divide and subdivide. Further, it will be observed that these divisions (called *bronchial tubes*) have a structure resembling that of the main tube, except that the rings of cartilage become gradually less and less perfect, till in the smallest tubes they entirely disappear.

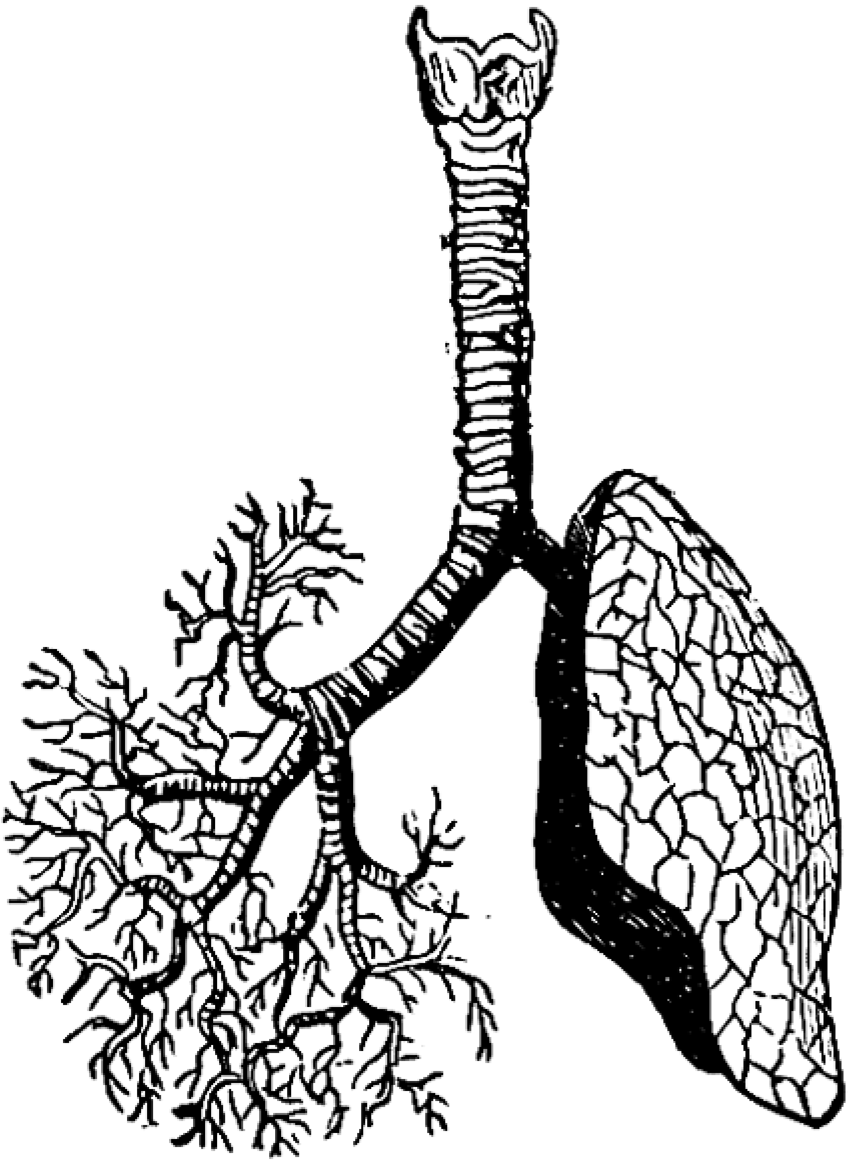

Fig. 178.—THE LUNGS AND WINDPIPE.
The Right Lung dissected to show the Bronchial Tubes.

A microscopic section of the lung shows that the smallest bronchial tubes terminate in bunches of air-cells, the very thin walls of which are surrounded by a close network of blood capillaries formed by the branching of the pulmonary artery.

Now let us briefly determine the nature of the air that is expelled from the lungs during respiration. Give a very deep expiration, allowing the air expired to pass into a cylindrical glass jar. Immediately thrust into the jar a lighted taper. The flame is extinguished, there not being sufficient oxygen in the air to support the combustion of the taper.

Give another slow but very deep expiration, and allow the air expired to pass through a glass tube into a little lime-water contained in a glass vessel. As the air bubbles through the lime-water a white precipitate of calcium carbonate is soon formed, proving that the expired air contains a very appreciable quantity of carbonic acid gas.

The observations and experiments suggested in the last few pages have taught us the following facts:—

1. The blood of the left side of the heart is of a bright red colour, while that of the right side is of a dark purplish colour.
2. Blood is brightened in colour by oxygen, and rendered darker by carbonic acid gas.
3. In the lungs the inspired air in brought into very close proximity with the blood, being separated only by the exceedingly thin walls of the air-cells and the blood capillaries.
4. The air exhaled from the lungs contains more carbonic acid gas and less oxygen than the ordinary atmospheric air.

In the light of these facts we are able to understand the true nature of respiration. The blood passing through the capillaries that surround the air cells of the lungs becomes richly charged with oxygen, and consequently of a bright red colour. This blood is returned to the left side of the heart through the pulmonary veins, and is then transmitted through the vessels of the system by means of the aorta and its various branches. As it passes through the capillaries of the different organs, and more especially in the muscles, it comes in contact with matter the carbon and hydrogen of which are converted into carbonic acid gas and water respectively, the chemical action being brought about by the oxygen conveyed from the lungs, principally by the hæmoglobin of the red corpuscles. In this way the blood is deprived of much of its oxygen, while at the same time it becomes richly charged with carbonic acid gas, and dark in colour. On returning to the right side of the heart it is propelled through the pulmonary arteries to the lungs; and, on reaching the capillaries round the air-cells, it liberates carbonic acid gas into the air-cells for expulsion by the lungs, receives a fresh supply of oxygen, and once more turns to a bright red colour.

Hence the left side of the heart, together with the arteries and veins connected with it, always contains bright red aerated blood; while the right side, and the arteries and veins communicating with it, always contain dark blood with less oxygen and more carbonic acid gas.

A few words must now be said concerning the mechanism of respiration in a mammal. First let us recall a few facts previously learnt. They are—

1. The lungs are contained in the thorax, and almost entirely fill the cavity.

2. The thorax is an air-tight cavity, and the lungs are inflated and stretched to fill the cavity by the pressure of the atmosphere acting through the trachea.

3. The floor of the chest is formed by the diaphragm, which is convex above, and consists of muscular fibres radiating from a central sheet of tendon.

4. The side walls of the chest are formed by the ribs, between which are the intercostal muscles.

Now, the act of inspiration is a purely muscular act. The muscles of the diaphragm contract, and, as a result, the partition becomes less arched, and the cavity of the chest consequently deeper. At the same time the outer set (for there are two distinct sets) of intercostal muscles contract, and, in conjunction with other muscles which we need not name, raise the ribs, bringing them into a more horizontal position, thus making the chest wider.

The capacity of the chest being thus enlarged, air passes down the trachea to restore the original pressure, thus more fully inflating the lungs.

When the contraction of the above-named muscles ceases, the walls of the chest, and the lungs, recoil by their own elasticity, thus expelling the air. Thus, it will be gathered that the action of expiration is not a muscular action; nevertheless certain muscles play a lesser part. For instance, the inner set of intercostals, by their contraction, depress the ribs, making the chest narrower; and at the same time the muscles which form the walls of the abdomen contract, exerting a pressure on the organs within, and these communicate the pressure to the under surface of the diaphragm, thus causing it to become more arched, and the thorax consequently shallower. However, though these muscles have but little to do with the expiratory act of ordinary quiet breathing, yet they play a considerable part in the case of the deep expirations of forced breathing.

7. MUSCULAR MOTION.

Muscle or flesh consists of bundles of fibres, and each fibre has the power of contracting when stimulated by an impulse conveyed to it by means of a nerve. Some, like those of the abdominal walls, are arranged in broad, flat

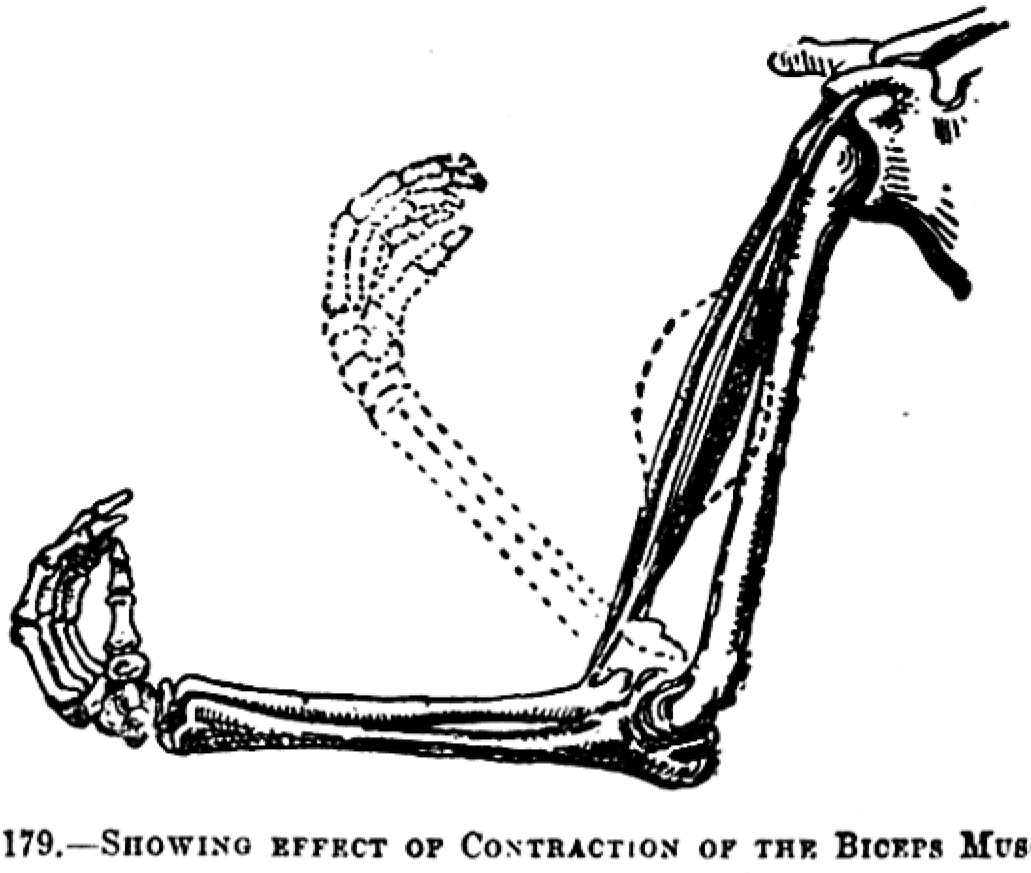

Fig. 179.—SHOWING EFFECT OF CONTRACTION OF THE BICEPS MUSCLE.

sheets, while the majority of the muscles that are attached to the movable bones of the skeleton are spindle-shaped.

When the individual fibres contract, the muscle as a whole becomes shorter and thicker, thus causing an approximation of the structures to which its ends are attached; and in this way motion and locomotion are brought about.

One end of a muscle is usually attached by a tendon to a fixed bone, and the other similarly connected with a movable one. Thus, when the fibres of the muscle contract, the latter bone, acting as a lever, is pulled towards the fixed origin of the opposite tendon. This action is well illustrated by the powerful biceps muscle of the arm, the upper tendon of which is connected with the shoulder, while the lower is inserted into the radius of the fore-arm (see Fig. 179).

Each muscle is capable of producing motion by contraction only, and thus it is that we find muscles arranged in antagonistic pairs or sets—one muscle or set of muscles to produce a certain movement, and the antagonistic muscle or set to bring about the opposite motion.

Some muscles are not connected with bones, but surround tubes or cavities, as in the heart, blood-vessels and digestive tube. The function of such muscles is evidently to reduce the size of the tube or cavity around which they are placed.

Muscles are classified into voluntary and involuntary. The former are those which *can* be made to contract by an effort of the will, while the latter are beyond our control. The muscles connected with the skeleton are voluntary, and those which exist in the walls of the internal organs are involuntary. All are controlled by nerves, whose fibres terminate within them, but while the muscles of the skeleton are under the influence of the brain and spinal cord, the involuntary muscles are controlled mainly by another set of nerves belonging to the "ganglionic system."

It must be remembered, however, that the action of voluntary muscles may be, and frequently is, purely involuntary. Thus, though we may blink the eyelid, swing the arm, breathe and walk by a distinct effort of the will, these acts are often performed involuntarily.

As examples of the action of involuntary muscles we may mention the beating of the heart, the last part of the act of swallowing, and the motions of the walls of the stomach and intestines.

8. EXCRETION.

We have seen that the vital functions of the animal body are always associated with a certain waste of material. It is necessary that this material should be eliminated from the blood, or even removed completely from the body. Special organs are concerned in the removal of such waste, and we speak of these collectively as the *excretory organs.*

It is clear from what we have learnt that the lungs come under this category, for they are the means by which carbonic acid gas and a certain amount of water are expelled from the system. The carbonic acid gas is a product of the oxidation of solid waste material. Water is also formed as the result of the oxidation of the hydrogen of waste matter, though the greater part of the water given off by the lungs results from the evaporation of the general moisture of the body from the moist surfaces of the air passages.

The skin also is an excretory structure, for it contains, in its deeper layer, a multitude of little *sweat glands* which have the power of separating a fluid from the blood circulating in capillaries round their thin walls. This fluid is the *sweat* or *perspiration*, and consists of water, in which is contained a small amount of dissolved salts, and a little fat and other organic matter. The glands open by means of the minute pores of the skin; and, as a rule, the water evaporates from the surface as fast as it is exuded, so that the perspiration is insensible. At other times, more especially during warm weather and violent exercise, the glands are more active, and the *visible* perspiration then accumulates on the skin.

The action of the glands is most important in assisting the maintenance of the normal temperature of the body, for in warm weather and during violent exercise they pour out a much larger quantity of water; and this, evaporating on the surface of the skin, tends to reduce the temperature.

The kidneys are very important excretory organs. They are situated at the back of the abdomen, one on each side of the vertebræ of the loins, with their concave sides turned towards the vertebræ. Each one receives aerated blood direct from the aorta by the *renal artery*, and after this blood has circulated through the capillaries of the organ, it is gathered up and transmitted to the vena cava inferior by the renal vein. The organ itself consists of a very complicated system of tubes and tubular glands, which separate nitrogenous waste material from the blood chiefly in the form of *urea* and *uric acid* dissolved in a large amount of water. The excretion (the urine) is conveyed from each kidney, by a tube called the ureter, into the bladder, from which it is periodically discharged.

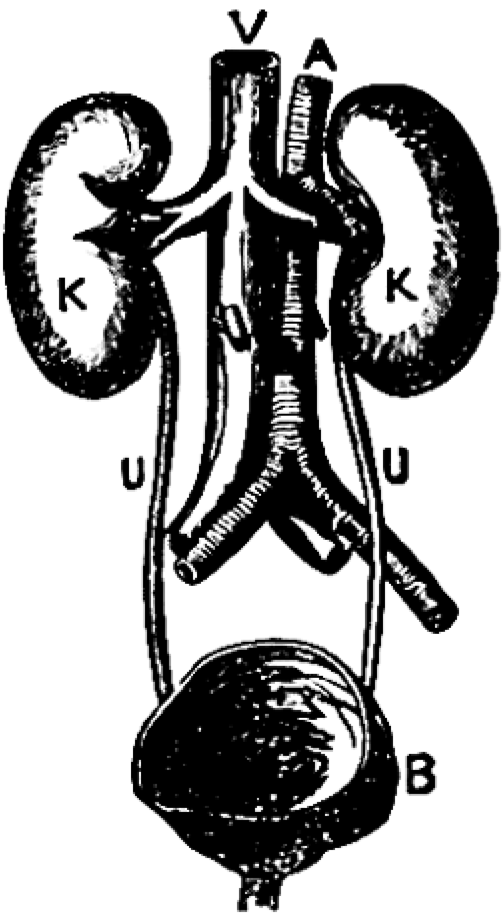

Fig. 180.—K K, The Kidneys; V, Large Vein (the Inferior Vena cava); A, Large Artery (the Aorta); U U, Ureters; B, The Bladder.

Questions.

1. On what food principles do (*a*) cattle, (*b*) dogs, depend for their sustenance? Which articles of food commonly supply these principles?

2. The uses of bone are, generally speaking, to protect delicate structures, to support weight, and to gain leverage. Illustrate this statement by a simple description of one example of each type.

3. In what way is the body-cavity of a mammal divided? Give a brief description of the arrangement of the internal organs in each division.

4. What is the use of food? What becomes of the various food materials after they have been digested?

5. What are the principal food materials in a suet pudding? In what parts of the body are these different materials digested?

6. Give a general description of the position, size, form and structure of the heart.

7. Describe what is seen when a sheep's heart is opened, and state briefly the uses of the structures observed.

8. The flow of liquids through the body is regulated in certain localities by valves. Explain the action of a valve, and indicate where they are to be found in the body.

9. Describe the course of the blood from the time it leaves the left ventricle until it again returns to this cavity, and give the names of the largest vessels through which it passes.

10. Give a brief description of the blood, and state clearly its uses in the body.

11. What changes take place in the blood as it circulates through the lungs? State exactly where these changes occur.

12. Give a general description of the form and position of the lungs, and also of the structures which immediately surround them.

13. What vessels enter and leave the lungs? What passes through each of these vessels? State how each vessel begins and how it terminates.

14. Describe the manner in which air is made to enter and leave the lungs during ordinary respiration.

15. What changes take place in the air of a badly ventilated room in which persons are living?

16. State briefly the use of the liver in the body. Give the general form and position of this organ.

17. What is meant by secretion? Give a brief description of the position and structure of any organ that secretes a fluid, and state the use of the fluid secreted.

18. Which of the internal organs are concerned in the removal of waste materials from the blood? Give a general description of these organs, and say what materials are removed by them.

APPENDIX.

SUGGESTIONS FOR PRACTICAL WORK.

This course of practical work may be commenced at any season of the year with Section I. of Chapter I.

The lessons are arranged to be each of about two hours duration.

In many cases the results obtained in an experiment performed in a lesson will be required in the next or a subsequent lesson.

ANY SEASON OF THE YEAR.

Lesson 1.

Based on the subject matter of Chapters I. and II.

Amœbae for examination can be obtained from the Natural History Specimen Supply Association and from Mr. H. Jessop, 30 Beckmead Avenue, Kenton, Middlesex.

They may be cultivated: Put 10 gms. of chopped hay into 1 litre of distilled water and steam for ¾ hour. Filter. Make filtrate just neutral to litmus paper by adding a few drops of sodium hydrate. When cold pour a small quantity into a glass trough, about 6 inches diameter, with a glass cover, leaving plenty of air-space, and inoculate each with a trace of soil. Leave for a day or two. The cultures may be kept indefinitely by adding one or two crushed wheat-grains once a month.

For microscopic examination clean cover glasses may be dropped on to the surface of the culture and then placed on microscopic slides, or a small quantity of the surface layer (best obtained in a loop made in a platinum wire) may be put on to a microscope slide and covered with a cover glass.*

Careful drawings should be made showing alterations in shape as food is absorbed.

For examination of **Blood Corpuscles** the finger should be pricked with a needle, a small quantity of blood put in the centre of a microscope slide and covered with a cover glass. The blood may be diluted with ·75 % salt solution. Diagrams should be made of the colourless corpuscles.

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* A cover glass should be gently lowered from one side of the drop to the other by means of a needle. Care is needed to avoid the inclusion of air-bubbles. There should be just sufficient liquid to fill the space beneath the cover glass.

Yeast may be obtained from a brewery or baker and cultivated. A small quantity should be mounted, examined microscopically, and diagrams made to show budding.

Cut some slices of raw potato, spread on their surface a little of the culture; then place them in a covered vessel and leave for a few days.

Lesson 2.

Based on the subject matter of Chapters II. and III.

Yeast—*continued.* Microscopic examination of yeast grown on potato will show that the cells now contain four smaller spherical bodies, each of which is a spore capable of resisting adverse conditions.

The experiment shown in Fig. 2 should be carried out in the light and in darkness, and the results compared.

Experiment, as in Fig. 3, should be made and some of the distillate tested for alcohol: Add some Iodine which has been dissolved in Potassium Iodide aqueous solution. Then add Potassium Hydrate (caustic potash) drop by drop until the colour disappears, when a fruity smell resembling pears will be noticed, and a yellow precipitate will gradually be formed of Iodoform.

Protococcus is very common on the bark of trees. This should be examined microscopically, mounted (1) in water, (2) in dilute glycerin (50 % water), (3) in iodine (in potassium iodide). Comparative results of the experiment shown in Fig. 6 should be obtained (1) with carbon-dioxide in the water and placed in the light, (2) with carbon-dioxide in the water and placed in the dark, (3) with carbon-dioxide removed from the water by boiling and then cooling.

Lesson 3.

Based on the subject matter of Chapter IV.

Compare the unicellular organisms so far described with the formation of:—

(1) A filament or row of cells, *e.g.* Spirogyra and many other pond-weeds.

(2) A plate of cells, *e.g.* the sea weed Ulva.

(3) Many different types of cells which can be seen by boiling some Rhubarb and carefully separating out a small piece on a slide for microscopic examination.

Sections of any available plant tissue, cut as directed on p. 30, will also show cells and tissues of different types for carrying out a variety of functions. A piece of the skin of a leaf should be stripped off, mounted, and examined. Diagrams should be made to show the cells and tissues observed.

Hydra can be kept in an aquarium of pond-water with water plants, if minute water animals are added from time to time. If water-fleas (Daphnia) are added with a pipette from time to time it is interesting to watch the Hydras catch and "eat" them. The water-fleas may be easily cultured in a glass vessel to which a few wheat-grains are occasionally added.

Cut off a small piece of weed with Hydra attached, place it on a slide in a drop of water and put a cover glass over it. If it is detached mount a small piece of weed with it.

Prepared slides of animal and plant tissues for further study can be obtained from Baird and Tatlock, London, or Flatters and Garnett, Manchester.

Some organic material, *e.g.* leaves, seeds, may be dried, and then further heated in a crucible until it catches fire, when most of it will burn away, leaving a residue of inorganic material known as ash.

Lesson 4.

Based on the subject matter of Chapter VI

Starch. Follow the directions given for starch in Chapter VI. Test for starch by applying Iodine solution to the cut surface of—peas, beans, maize, wheat, rice, crocus corm.

Heat some starch in a test-tube and notice the formation of water at the upper cool end. Heat some strongly in a crucible and observe that it blackens, proving the presence of carbon, then catches fire and will all burn away if pure.

Starch is rendered soluble in the plant by an enzyme diastase, which can be purchased. Prepare some dilute starch paste, by stirring some starch with a little water to mix it well, then pour on to it while stirring some boiling water until it becomes gelatinous and somewhat transparent.

Take a series of test-tubes in a stand and put an equal quantity of starch paste into them. To all except one add a solution of diastase, increasing the quantity in the series. If no diastase is available, just spit into the starch-solution, and the ptylase of the saliva will produce enough sugar to give Fehling's test within 15 minutes.

Fill the test-tubes to the same level with water and leave in a warm place for a day or two. Remove an equal quantity of the mixture from each test-tube, add a little Iodine solution, and note the variation in the colour produced, which indicates that different quantities of starch are now present.

Take another portion of the mixture in test-tubes, add Fehling's Solution, and heat gently: the formation of a yellow precipitate, changing to orange and red on continued heating, indicates the presence of soluble sugar into which the starch has been converted.

Chlorophyll. Place some green leaves in methylated spirit. Boil some in water, then place them in methylated spirit. Note that chlorophyll is removed much more quickly and completely in the latter case because the leaves were dead.

Place some chlorophyll solution in a test-tube, look through it and observe the green colour. Cover the part of the test-tube occupied by the solution with black paper and look down on to the surface, note blood-red colour, therefore fluorescent nature of chlorophyll.

Chlorophyll is formed in chloroplasts which vary in shape and size. Examine microscopically cells of Spirogyra, zygnema, a moss leaf, and other green tissue.

Cellulose of cell walls should be examined as on p. 22.

Sugar. The above test should be applied to solutions made from crushed grapes and carrot and the presence of sugar observed.

Cane sugar is present in Beetroot, which does not cause this reaction with Fehling's Solution unless first boiled with dilute hydrochloric acid for about 15 minutes, and then rendered neutral with caustic soda as shown by litmus paper.

Oil can easily be detected in nuts by crushing them between paper and noting the characteristic greasy mark.

Presence of **Nitrogen** should be determined as on p. 23.

Proteids can be found in Peas and Beans by warming some solution from them gently with a little nitric acid and when cool again adding ammonia which will change the yellow colour to orange. This is the Xanthoproteic Reaction. A little Millon's reagent added to a solution from Peas or Beans and gently heated gives a brick red precipitate, again showing proteids are present.

Note on Local Vegetation (pages 124-7). At all seasons of the year as many plants as possible should be examined from situations such as—a pond, river, river-bank, meadow, hedge, common, moor, chalky district, sea shore, oak wood, beech wood. Their distinguishing features should be noted, and any characters which appear useful in connection with the particular type of situation.

AUTUMN.

Lesson 5.

Based on the subject matter of Chapter VII.

The Fern. Draw the external appearance of rhizome with young fronds, showing leaf-bases, scales, and roots. Draw part of a leaf, upper and under surface, to show the veining and sori.

Draw transverse sections of rhizome and petiole. See Figs. 10 and 12.

Cut a transverse section of a petiole and examine microscopically and draw in detail a sector. The structure shown in Fig. 15 is usually considered to be a meristele because it is bounded by an endodermis, the cells immediately inside this are the pericycle, and amongst the wood some remain parenchyma, keeping their living contents.

A longitudinal section should be cut through a meristele and the types of cells carefully drawn.

Mount a small root with tip and note the root cap and root hairs.

Cut a transverse section of a root and draw a plan to show the arrangement of the tissues.

Lesson 6.

Based on the subject matter of Chapter VII.

The Fern—*continued.* Strip off a piece of the upper and lower epidermis from a leaf and examine microscopically (see Fig. 16).

Cut a transverse section of a leaf through a sorus and draw a piece to show the leaf structure, sporangia and indusium. Some young fronds should be selected to obtain developing sporangia.

Mount fresh ripe sporangia in methylated spirit and note explosive dehiscence.

Germinate spores as directed in pp. 36-7. These prothalli will not be developed until the following summer, but specimens can usually be obtained from botanical gardens. For examination prothalli should be carefully washed and mounted whole, under surface upwards; when the structures, as in Figs. 18*c*, 19, and 20, can be seen. As this is surface view in many cases the archegonia will only show the tip of the neck, *i.e.* four cells round the neck canal cell.

Lesson 7.

Based on the subject matter of Chapter X.

The Frog. The autumn is a good time to study the adult frog (see p. 154).

Immerse an adult frog for 15 minutes at least in chloroform vapour.

Obtain an enamel pie dish half full of hardened paraffin wax, fill with water, lay the dead frog on its back on the wax under water. Fasten it down, slightly stretched, by four pins, one through each limb. The pins should slant obliquely away from the frog.

Cut through the skin with a sharp scalpel along the middle line. Separate the skin, turn the flaps outwards and pin them back. Pinch up the muscular body wall with forceps, make two cuts with scissors a little to each side of the middle line through into the body cavity. Continue the cuts backwards and forwards.

In the female frog note (1) two ovaries, which are large bodies of irregular shape, being a mass of eggs, (2) the oviducts, which are much-coiled tubes.

Water causes the jelly round the eggs to swell greatly, therefore remove the ovaries and oviducts to see the other organs.

In the male frog note two testes, which are vivid and pale yellow with branched yellow fat bodies, situated near the kidneys.

Note the parts in Fig. 138, also two kidneys with ducts leading together with the bladder into the rectum, the lowest part of the large intestine. Make a diagram of the dissected frog to show the parts.

Turn the liver forwards and note the stomach lying beneath its left lobe. Pass the handle of a mounted needle through the mouth and down the œsophagus into the stomach. Cut open the stomach longitudinally and note the handle of the needle in it, also folds of mucous membrane lining the stomach which increase the extent of the surface.

To trace the bile duct turn the liver forwards so that the point of attachment of the gall bladder is seen. Slit up the intestine for $\frac{3}{4}$ inch from stomach along the convex border and wash out the contents, then squeeze the gall bladder to drive the bile along the duct into the intestine. Insert a bristle into the opening of the duct and note the strong wavy transverse folds of mucous membrane.

Note the auricles and ventricles of the heart and the vessels connected with it, see p. 215. Note that the pulsation of the heart continues some time after the frog has been killed.

Lesson 8.

Based on the subject matter of Chapter X.

The Frog—*continued.* Mount a drop of blood and examine microscopically (see p. 217).

Obtain a frog's skeleton, as directed on p. 158, examine it carefully, and draw the parts.

Skeletons can be obtained from naturalists if desired.

Lesson 9.

Based on the subject matter of Chapter VIII.

The Root. See p. 45. Root hairs and the root cap can be seen well if mustard seeds are germinated on damp blotting paper between two saucers. Some roots should be obtained and drawn to show the axis, rootlets and, if pea or bean roots are available, the tubercles.

Draw roots of carrot, radish, turnip, dahlia, and climbing roots of ivy.

Cut a carrot transversely and longitudinally to show that the rootlets emerge from the central cylinder.

Germinate grains of maize and barley and draw stages of development, noting the adventitious roots.

Lesson 10.

Based on the subject matter of Chapter VIII.

The Stem. Obtain any leafy branch and draw to show the parts and their arrangement (see Fig. 30).

Creeping and underground stems, bulbs, and corms should be procured and drawn, noting carefully all their parts, their origin and age. See pp. 54-8.

Lesson 11.

Based on the subject matter of Chapter VIII.

The Stem—*continued.* Plants with spines and prickles should be examined and the exact nature of the spine noted. See pp. 58-60.

Cut stems of sunflower, elder, and elm, examine them as directed on pp. 60-62, and draw plans of them.

Lesson 12.

Based on the subject matter of Chapter VIII.

The Stem—*continued.* Carry out the experiments on p. 62. Experiments 1 and 2 can also be performed with twigs cut and placed in water.

Put any available leafy branches in water coloured with a few drops of red ink or eosin. After a few days cut the stem across and note that the wood is coloured red, examine the leaf carefully, also cutting a few sections of it, and note that the wood of the veins is also coloured red.

Cut a monocotyledon stem as described, pp. 63-4, and draw a plan. Specimens of these should also be put into coloured solutions and the wood noticed.

WINTER.

Lesson 13.

Based on the subject matter of Chapter VIII.

Fruits. Examine as many fruits as possible and draw transverse and longitudinal sections of them, noting the number of carpels, arrangement of seeds, whether succulent or dry, dehiscent or indehiscent, any parts other than the ovary.

Lesson 14.

Based on the subject matter of Chapter VIII.

Fruits—*continued.* As many examples of different methods of seed disposal (pp. 103-6) should be examined and drawn as are available.

Lesson 15.

Based on the subject matter of Chapter XI.

The Bird. Buy a pigeon with feathers. Pluck it except one wing. Draw different kinds of feathers and examine a piece microscopically. See pp. 162-5.

Draw the foot, beak, and eye. Feet and beaks of other domestic birds or museum specimens should be examined. Note webbed foot of duck for swimming.

Keep the pigeon in methylated spirit or formalin.

Lesson 16.

Based on the subject matter of Chapter XI.

The Bird—*continued.* Dissect in a pie dish under water as for the frog, first pinning the bird out.

Dissection of the Air-sacs: Make a median ventral incision through the skin of the neck and pin out the flaps. Note the œsophagus, a wide, fleshy, median tube, and the trachea, which is easily recognised by the close set rings surrounding it.

Separate the trachea from the surrounding tissue, ligature it, cut it open at about the middle of its length, pass a blow pipe or bent glass tube down the trachea through the slit, and tie it in. Inflate the lungs and air-sacs through the pipe and tighten ligature to keep them blown up. Make a mid-ventral incision through the skin from the posterior edge of the sternum to the end of the body and a transverse incision along the posterior edge of the sternum. Carry the cuts through the muscles, turn flaps outwards, and find the nine air-sacs.

Dissection of the Digestive System. Open the mouth slightly. Cut through the cheek parallel to the jaw for half an inch on each side and turn down the floor of the mouth to expose the cavity. Note tongue, glottis, and aperture behind it, and large entrance to the œsophagus behind the glottis. Detach the sternum with a scalpel and remove it. Note heart, lungs, liver, and great omentum. The last is a fold of membrane loaded with fat; lift it to find the gizzard, intestines, and stomach. Make a diagram of the dissection. See Fig. 148.

Lesson 17.

Based on the subject matter of Chapter XI.

The Bird—*continued.* Mount and examine microscopically a little blood. See p. 218.

The Skeleton. The bones from a cooked pigeon or fowl may be kept, boiled, and all the flesh removed, then steeped in a clear solution of bleaching powder to whiten and preserve them, washed in water, dried, and fastened together with wire, as shown in Fig. 149.

Diagrams of characteristic bones should be made, including the wing bones and the wing with feathers. A bone should be cracked across and the air holes noted.

Lesson 18.

Based on the subject matter of Chapter XII.

Mammals. A live rabbit should be kept and its habits noticed. The bones should be obtained from a cooked animal, as directed for a pigeon. Draw the skull and other characteristic bones. In the skull note carefully the attachment to the spinal column, jaw bones with teeth, and brain case.

Lesson 19.

Based on the subject matter of Chapter XII.

Mammals—*continued.* A sheep's head and limbs can be obtained and examined as directed on pp. 184-5. Observations on other domestic animals should be made. Visits to Natural History Museums are a great help.

Lesson 20.

Based on the subject matter of Chapter XIII.

Physiology. In considering this chapter reference should be made directly to the human body as far as possible and also to the foregoing dissections of animals.

A sheep's heart should be dissected as described on pp. 208-12.

Buy the so-called lights (animals' lungs) from a butcher and note lung structure, pp. 218-19.

Experiments on respiration described on p. 220 should be performed.

SPRING.

Lesson 21.

Based on the subject matter of Chapter VIII.

Buds. Obtain twigs from our common trees. Draw a piece of each to show the terminal bud, if present, lateral buds, and their arrangement, dormant buds, breathing pores, leaf scars and girdle scars (where scale leaves fell from buds of previous years, hence the age of the parts can be determined).

Lesson 22.

Based on the subject matter of Chapter VIII.

Buds—*continued.* Twigs should be gathered in January or February, and it is a good plan to keep them in water indoors until the buds just begin to burst, when transverse and longitudinal sections, as directed on p. 115, can be made more easily.

A large bud should also be dissected and the parts placed on a sheet of paper in their relative positions, and a diagram made of this plan.

Examine a Brussels Sprout in the same way; here the parts are larger and the young foliage leaves with buds in their axils can be seen plainly.

Lesson 23.

Based on the subject matter of Chapter VIII.

Our Forest Trees (pp. 115-24). Their study should be begun now. The general form and appearance, branching (the trunk should be examined out of doors), twigs, and buds can all be gathered and considered. Two or three pages should be set aside for each tree and the leaves, flowers, fruits, seeds and seedlings added as they become available. They can be dealt with in lessons dealing with these parts of plants.

Lesson 24.

Based on the subject matter of Chapter VIII.

Our Forest Trees—*continued.* Some evergreen trees should be noted. In cone-bearing trees, cones of different ages may be present, *e.g.* seed-bearing cones of Pine take three years to mature. They should be studied in the open and from parts collected.

Lesson 25.

Based on the subject matter of Chapter VIII.

The Germination of the Seed. Examine bean seeds and maize grains carefully, as directed on pp. 106-11.

Other seeds *e.g.* mustard, cress, sunflower, peas, sycamore, acorns, onion, castor oil, should also be examined and germinated. Note that in some the cotyledons come above ground and become the first green leaves.

The stages in germination can be observed very conveniently by lining a glass jar with blotting paper, filling with sawdust and placing the seeds round the jar between the blotting paper and glass. They can thus be watched without disturbance or removal. Care must be taken that a suitable amount of water be supplied.

Lesson 26.

Based on the subject matter of Chapter VIII.

The Growth of a Plant. The experiments described on pp. 41-5 should be carried out.

For experiment Fig. 24 cuttings *e.g.* fuchsia or tradescantia can be used with advantage. If seedlings are used the cotyledons should be removed as soon as possible.

The jars should be covered with black paper, unless opaque, so that the roots are in the dark, and green algae do not grow in the solution. Other solutions should be tried, *e.g.* omit the iron chloride from the solution on p. 43 and the green colour will cease to be made as the new leaves grow, owing to the absence of iron from the food.

Replace potassium nitrate by potassium chloride, and a very small stunted plant will result owing to the lack of nitrogen in its food.

Lesson 27.

Based on the subject matter of Chapters VIII. and X.

The Frog—*continued.* At the beginning of March eggs should be obtained. Draw as in Figs. 130-31. Note in each egg black embryo and white yolk.

These must be kept and examined in succeeding lessons, stages being drawn to show alteration of shape of egg until tadpole emerges (Fig. 132), and also later stages, see Figs. 133-5, as they appear.

The Flower. The study of flowers should now be begun and continued as specimens become available.

Flowers of Broad Bean, Gorse, Broom, Laburnum, Lupin should be examined with careful reference to pp. 74-6. Note that in some cases the ten stamen filaments are all united, in others the one at the top remains free.

Large vertical sections should be drawn. See Fig. 59. A flower of each kind should be carefully taken to pieces and the parts placed on gummed paper in their respective positions, the five sepals in a circle, the five petals inside them, and alternating with them, then the ten stamens, five alternating with the petals and five opposite to them, and the pistil in the centre. If a piece of blotting paper be placed on top and the whole fastened and pressed in a note-book a permanent record of the flower parts is obtained.

Transverse sections of ovaries should be drawn.

Lesson 28.

Based on the subject matter of Chapter VIII.

The Flower—*continued.* Flowers of Willow will now be available, the sexual organs of plants, pp. 81-3, should be studied. Begonias could also be examined now.

Pollen grains from different flowers should be examined microscopically and germinated. See p. 83.

The study of cross-pollination should be begun (p. 84). Many wind pollinated flowers come out in the Spring (p. 87). Note that Willow is pollinated by insects. Primroses are also available quite early (p. 95).

Large diagrams of flowers should be made to show how they are adapted to the particular type of pollination, and in the case of insect-pollinated flowers, how the honey is obtained, the pollen received from the anthers and deposited on the stigmas. A large vertical section with an arrow inserted to show the path taken by the insect usually shows these points quite well.

SUMMER.

Lesson 29.

Based on the subject matter of Chapter IX.

Insect Life. Look for eggs of cabbage white butterfly on backs of cabbage or nasturtium leaves in May or July. Examine carefully with a hand lens. Keep the eggs as directed on pp. 136-7, and watch the caterpillar developing, making careful drawings once a week (hand lens should be used). Note the process of shedding the skin. See p. 140.

Other insects should also be kept and watched, *e.g.* caterpillars of Magpie Moth can be obtained from privet in April or May, and the life cycle will be completed to the laying of eggs in June.

A large drawing of the head, walking leg and pro-leg should be made and a moulted skin mounted and examined microscopically.

Lesson 30.

Based on the subject matter of Chapter IX.

Insect Life—*continued.* Watch the development of the chrysalis and draw it.

If the eggs were obtained in May the butterflies will emerge in July or early August. The emergence of the insect should be watched, and stages drawn, also a perfect butterfly. See Fig. 113.

Butterflies can easily be killed for examination by putting in an enclosed space with a little ammonia. The parts should be observed and drawn as directed on pp. 132-5.

Differences between the Moth and Butterfly should be noted.

The Ichneumon Fly can readily be observed as directed on p. 144. It is an interesting parasite, one insect living on another.

Lesson 31.

Based on the subject matter of Chapter VIII.

The Leaf. Take any leaf, strip off the upper and lower epidermis, examine microscopically, and draw; note Fig. 46.

Experiment of Fig. 47 should be performed with a seedling or cut branch. A small drop of oil should be put on the surface of the water in the open tube to prevent evaporation. The apparatus may be weighed at the beginning and end of the experiment to show that the loss in weight due to the loss of water vapour from the leaves is equal to the decrease of water due to absorption by the roots or cut branch.

That water vapour is given off from leaves can be seen by placing a few under a bell jar or other glass vessel, when the inside will shortly become misty owing to the water vapour condensing upon it. For this purpose a leafy branch can be put through a cork and this placed in a flask of water, or a small plant in a pot can be used if the surface of the soil and pot be covered with tin foil or rubber to prevent evaporation. Either of these may be weighed and the loss in a given time and under definite conditions recorded.

A very convenient method of seeing the absorption of water to replace that lost in transpiration is to take a flask fitted with a 2-holed cork; through one hole pass a leafy branch, and through the other a piece of tubing bent at right angles, with a scale behind the free limb. Fill with water, and as transpiration goes on the water will recede from the open end of the glass tube.

Lesson 32.

Based on the subject matter of Chapter VIII.

The Leaf—*continued.* Carry out experiment Fig. 48 carefully with several different kinds of leaves, including a variegated one, of which a coloured plan should be made before and after.

Reference should be made to experiments in Chapter III., and note that green plants in the sunlight take in carbon dioxide from the atmosphere, and with water starch is formed and oxygen given out.

Examine as many leaves as obtainable, including leaves from our forest trees (pp. 115-24), draw, classify, and describe. See pp. 68-74. Note carefully the leaf arrangement on the stem and that the leaves most obviously show adaptations to the kind of situation in which the plant grows. See pp. 124-7.

Lesson 33.

Based on the subject matter of Chapter VIII.

Flowers—*continued.* The study of flowers should now be continued. Note the directions given in Lesson XXVIII.

White campion has unisexual flowers, and the stamens and carpels show well.

Examine a Buttercup with reference to Fig. 60, noting carefully the shape of the receptacle and the separate carpels.

Arum can also be obtained in May (see p. 93), columbine (see p. 90), and some members of the pea and bean group (see p. 91).

Lesson 34.

Based on the subject matter of Chapter VIII.

Climbing Plants. Climbing plants will now be procurable. See pp. 52-4. As many as possible should be examined and drawn; note carefully the manner of climbing, the organs concerned and their origin.

Lesson 35.

Based on the subject matter of Chapter VIII.

Flowers—*continued.* Diagrams of the types of inflorescence given on pp. 78-80 should be drawn from definite examples, which will be easily obtainable at this season.

Lesson 36.

Based on the subject matter of Chapter VIII.

Flowers—*continued.* The study of flowers and pollination (pp. 81-97) should be continued now, with such examples as Vallisneria (p. 85).

Grasses or Cereals (p. 86), Evening Pirmrose (p. 90), Sage (p. 91), Barberry (p. 92), and composite flowers (p. 96).

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